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Investigation of Seismicity and Related Effects at NASA Ames-Dryden Flight Research Facility, Computer Center, Edwards, California

Robert D. Cousineau, Richard Crook, Jr., and David J. Leeds

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Robert D. Cousineau, Richard Crook, Jr., and David J. Leeds
Soils International, San Gabriel, California

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FOREWORD

This report was prepared under the general supervision of Mr. Karl F. Anderson of NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California and Dr. B. Samuel Tanenbaum, Dean of Faculty, Harvey Mudd College, Claremont, California, Collaborators in the investigation. The investigation was sponsored by and technical direction and review was provided by Dr. Kajal K. Gupta of NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California.

Principal investigators were Robert D. Cousineau, Civil Engineer and Principal of Soils International of San Gabriel, California, Richard Crook, Jr., Geologist, and David J. Leeds, Engineering Seismologist.

The findings, conclusions and recommendations represent the professional opinions of the principal investigators as indicated by their signatures below.

The investigation was conducted in accordance with generally accepted engineering and geologic procedures and, in the opinion of the undersigned, the accompanying report has been substantiated by mathematical data in conformity with generally accepted principles of engineering and geological professions and presents fairly the information set forth in the Interchange for Joint Research, as modified by agreements between the coordinators and the principal investigators.

Principal Investigators:

Robert D. Cousineau, RCE 24269

Richard Crook, Jr.

Richard Crook, Jr.
Engineering Geologist, EG 924

David J. Leeds
Engineering Geologist, EG 373
Geophysicist GP 17

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PLATES

TABLES

1. INTRODUCTION/GENERAL

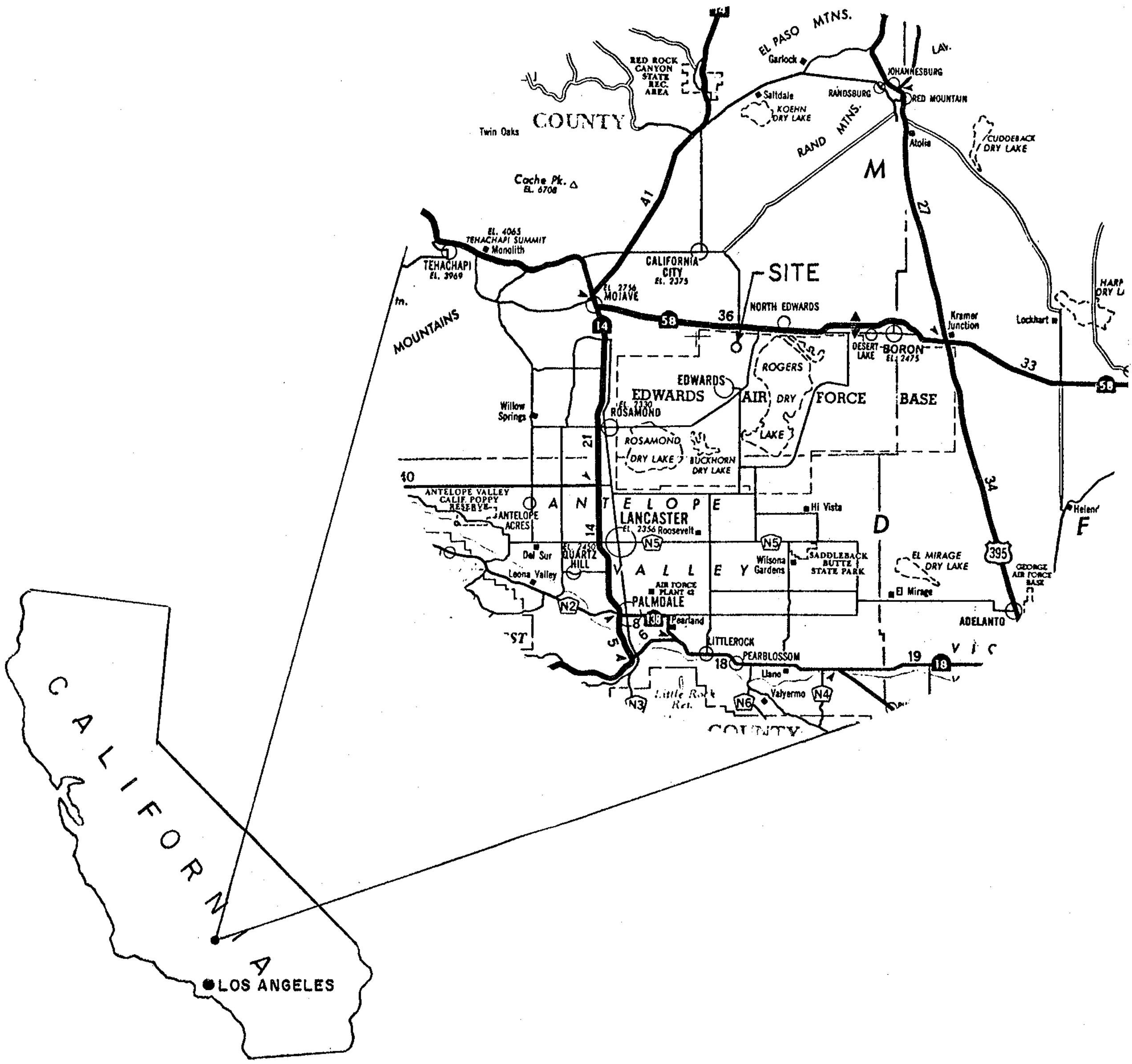
This report provides criteria for seismic evaluation at construction sites at the NASA Ames-Dryden Flight Research Facility located at Edwards Air Force Base, Mojave Desert Area, California.

1.1 Scope

This geological and seismological investigation is based upon a modest amount of field geological surveys, reviews of published literature, earthquake catalogs and reports, and interviews with professionals familiar with the area. Site soils and foundation data are further supported by previous investigations by others. The results of the investigation are presented as seismic design criteria, with design values of the pertinent ground motion parameters, probability of recurrence, and recommended analogous time-history accelerograms with their corresponding spectra. The recommendations apply specifically to the computer center site and should not be extrapolated to other sites with varying foundation/geologic conditions or different seismic environments.

1.2. Location

The project site lies in the west-central portion of the Mojave Desert Province, California, approximately 17 miles southeast of the town of Mojave (Plate 1.1). The NASA Dryden Facility and Computer Center is on the west edge of Rogers Lake at the north edge of the Air Force facilities on Edwards Air Force Base.



SITE LOCATION MAP

Plate 1.1

2. GEOLOGY

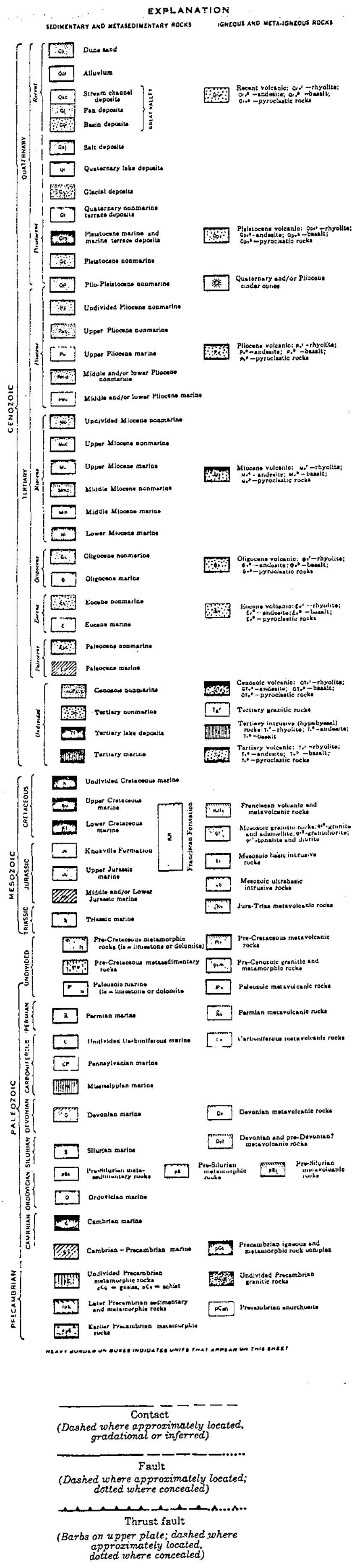
2.1 Regional Geology

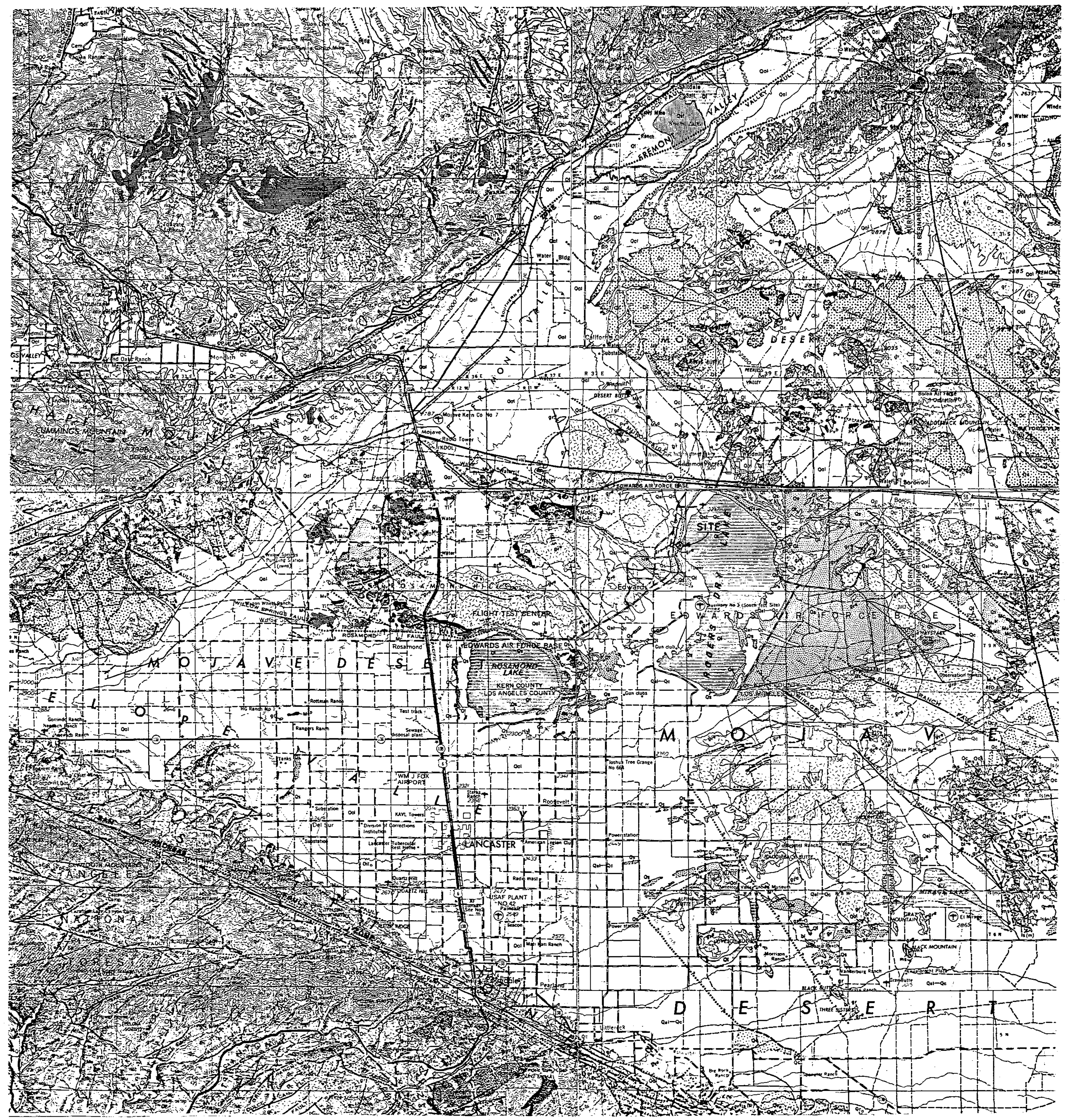
The Mojave Desert Province (see Regional Geologic Map, Plate 2.1, is a triangular-shaped block of regionally distinct geology and geomorphology that, in the vicinity of the site, is bounded on the north by the northeast-trending Garlock fault and on the south by the southeast-trending San Andreas fault (Hewett, 1954). In this region (Plate 2.1) the block is a plain that slopes gently eastward to the town of Barstow. This plain is dotted with numerous isolated hills and scattered ridges and local mountain masses all consisting of crystalline basement rock.

Parts of this plain are smooth rock surfaces with a sparse cover of debris (pediments), but large parts are underlain by deep fault-bounded subsurface valleys or basins filled with alluvium and lake deposits (D. J. Ponti, oral communication, 1983). The entire Mojave Desert Province is characterized by internal drainage, hence several of the valleys and basins in this area contain dry lakes or playas at their surface. Among the larger of these are the nearby Rogers and Rosamond Lakes.

Rocks of the western Mojave Desert can be divided into three main divisions: (1) crystalline rock of pre-Tertiary age; (2) sedimentary and volcanic rocks of Tertiary age; and (3) sediments of Quaternary age.

The crystalline rocks are largely plutonic and consist primarily of quartz monzonite with a few large granite bodies and small localized inclusions of hornblende diorite (Dibblee, 1967). Near the regional boundaries of the block, adjacent to the San Andreas and Garlock faults, the plutonic rocks contain small to large pendants (inclusions) of older metamorphic rocks.





REGIONAL GEOLOGIC MAP

Taken from Bakersfield, Los Angeles, San Bernardino & Trona California Division Mines and Geology Map Sheets.

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

Plate 2.1

The sedimentary and volcanic rocks of Tertiary age include conglomerates, sandstones, shales, chemical sediments, tuffs, breccias and lava flows and plugs ranging in composition from rhyolite to basalt. These rocks rest upon a deeply eroded surface of the crystalline rock. With the exception of a marine and brackish-water formation at the west end of the region, all sedimentary units in this portion of the Mojave Desert are non-marine, as are the lava flows.

The Quaternary age sediments are mainly alluvial deposits that fill the major depressions of this region. They range from coarse fanglomerate to sand, silt and locally to fine clay. In most places these sediments rest unconformably on rocks of pre-Tertiary age. Locally these sediments are covered with a thin veneer of wind blown sand. In the areas along the east and south edges of Rogers and Rosamond Lakes this sand has been deposited as dunes by the prevailing westerly winds.

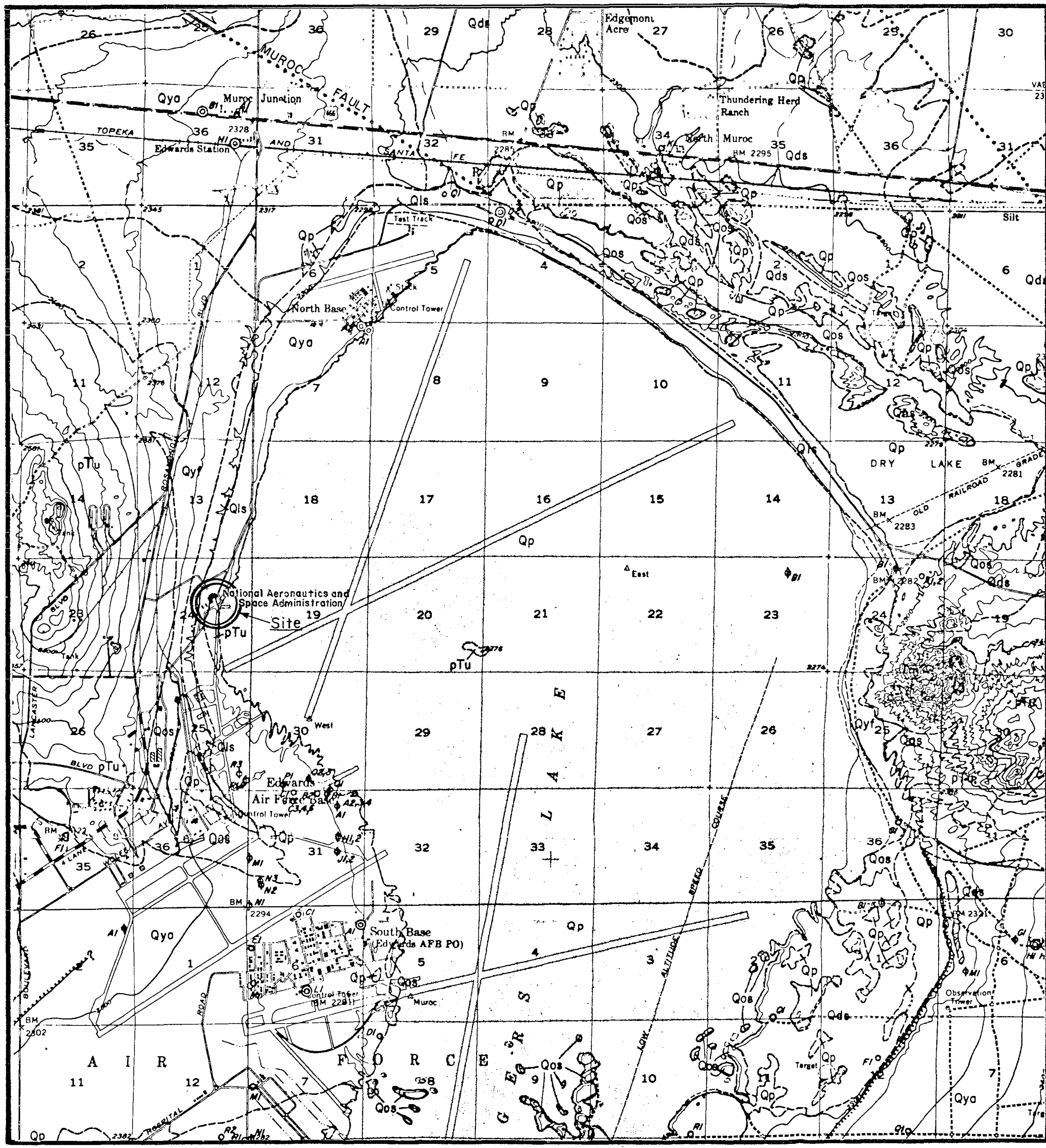
Prior to and contemporaneous with the deposition of the Tertiary age sediments the Mojave block was broken into a series of east-trending basins and elevated blocks by faulting. On-going deformation tilted, folded and faulted the Tertiary sediments. The Quaternary deposits that cover the basins and lap onto the eroded surface of Tertiary and pre-Tertiary rocks, in the elevated areas, are themselves locally deformed in the same manner, mostly near faults, but to a much lesser degree. This indicates that tectonic deformation of the Mojave block has more or less been continuous since the Mesozoic and has continued to the present.

Most of this deformation has been caused by and is localized along the major bounding faults and along the numerous northwest-trending faults within the block. The types of faults include a complete range: strike-slip (both right and left-lateral); reverse or thrust; normal; and combined strike-slip/reverse or strike-slip/normal.

2.2 Local and Site Geology

The NASA Dryden test facility is situated on a gently sloping pediment that rises in a westerly direction for a distance of approximately 6000 feet to a low north-trending ridge of crystalline rock (Plate 2.2). The site is bounded on the east by the Rogers Lake playa.

The pediment is developed on crystalline plutonic rock consisting of quartz monzonite with local inclusions of hornblende diorite, as exposed in the footing excavations for the NASA Data Analysis Facility. Foundation investigations and previous mapping (Dutcher, Bader and Hiltgen, 1962, and Appendix A) on the site indicate that crystalline rock is within 0 to 7 feet of the ground surface under some of the NASA installation. However, logs of water wells both north and south of the site (Dutcher, Bader and Hiltgen, 1962) indicate that the rock surface slopes away from the site. Two and a half miles north of the site the rock surface is at a depth greater than 200 feet, and one and a half miles south of the site it is at a depth of 90 to 125 feet. The configuration of this surface is not known in detail, therefore it may be deeper than 7 feet under uninvestigated portions of the site.



EXPLANATION

Qya	Younger alluvium
Qyf	Younger fanglomerate
Qls	Lake shore deposits
Qp	Playa deposits
Qds	Dune sand
Qoa	Older alluvium
Qof	Older fanglomerate
Qos	Older dune sand
pTu	undifferentiated basement complex primarily quartz monzonite
	geologic contact, approximate
	fault, dotted where concealed arrows indicate relative horizontal displacement

N

0 0.5 1 2 3

SCALE IN MILES

Contour Interval 25 feet

GEOLOGIC MAP OF PORTION OF EDWARDS AIR FORCE BASE

PLATE 2.2

Foundation investigation reports (see References) prepared for projects on the site indicate that the crystalline rock is highly weathered to depths of 5 to 15 feet. See Appendix A for typical borings. However, high density values obtained for this rock indicate that it is sufficiently coherent and competent for structural foundations and should transmit seismic energy without altering its "rock characteristics."

The surficial deposits overlying the crystalline rock on the site have been mapped as alluvium (Dutcher, Bader and Hiltgen, 1962). Foundation investigation reports indicate that these materials are predominantly moderately firm to firm, dense, medium to fine-grained, silty sand with localized lenses of clayey silt and gravel.

The rock surface drops eastward from the site beneath the surface of Rogers Lake. Here the rock is overlain by playa deposits consisting predominantly of clay, silt and fine sand. There is no subsurface information as to the thickness of these materials in the area of the site.

Although groundwater exists in the area, it generally is found in the loose younger Quaternary deposits (Dutcher, Bader and Hiltgen, 1962). Crystalline rock normally does not contain much groundwater and none was encountered in any of the exploratory borings on the site (Appendix A).

Owing to the shallow surface gradient and small drainage area the site should not experience runoff in quantities large enough to cause flooding problems.

2.3 Regional Tectonics

The Mojave block is both bounded by and internally cut by faults that have been active through the Pleistocene and into the Holocene or last 13,000 years (Sieh, 1978; Burke, 1978, 1979, and 1979a; California Division of Mines and Geology, 1963, 1965, 1969 and 1969a; Jennings, 1975; Ponti and Burke, 1980; Ponti, Burke and Hedel, 1981; Clark, 1973; Ross, 1969; Dibblee, 1961, 1967; and Guptil and others, 1979). Analysis of the geometric configuration, type and sense of displacements on these faults indicate that the Mojave block and adjacent regions have been subjected to north-south compression and east-west extension during this time. Additionally, seismic characteristics of recorded earthquakes in the region suggest that these regional stresses are still present.

This regional stress system has resulted in a consistent pattern of right-lateral displacements on northwest-trending faults and left-lateral displacements on northeast-trending faults. North or east-trending faults in this system generally display normal or reverse dip-slip displacements.

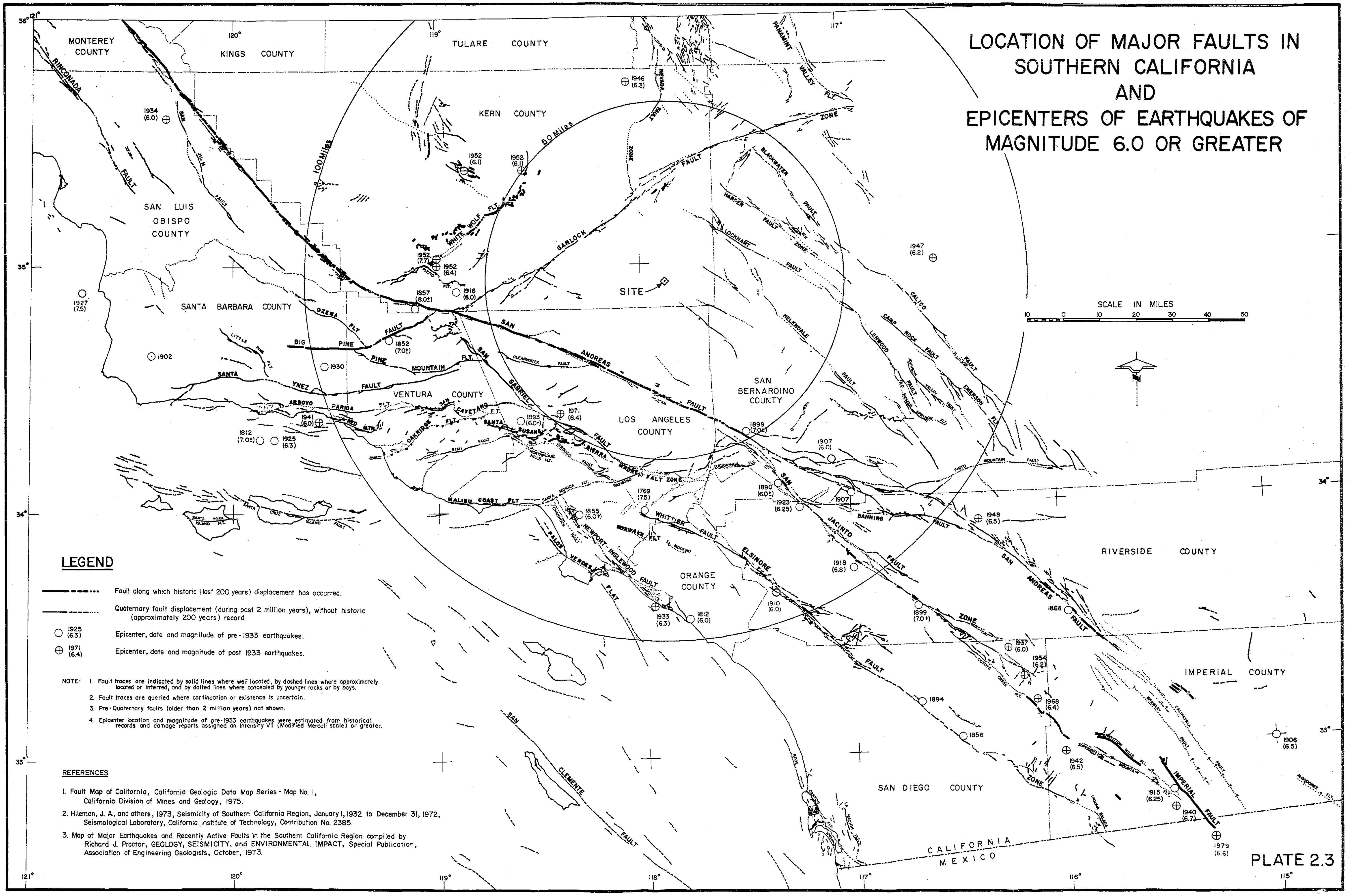
Whereas the two major bounding faults of the Mojave block, the San Andreas and the Garlock, are characterized primarily by strike-slip (horizontal) movement, most of the faults within the block appear to accommodate regional stresses with a combination of strike-slip and dip-slip movement (Jennings, 1975; Cummings, 1981; Hill and others, 1980; Hill and Beeby, 1977). This is characteristic of most of the smaller faults in the vicinity of the site.

The regional stress pattern described above is the resultant stress field derived from the relative movement of the Pacific Plate (northwest relative motion) with regard to the North American Plate (southeast relative motion). The boundary between these plates is the San Andreas fault. The Garlock is a primary conjugate fault to this system whereas the northwest-trending interior faults are secondary conjugates of this system.

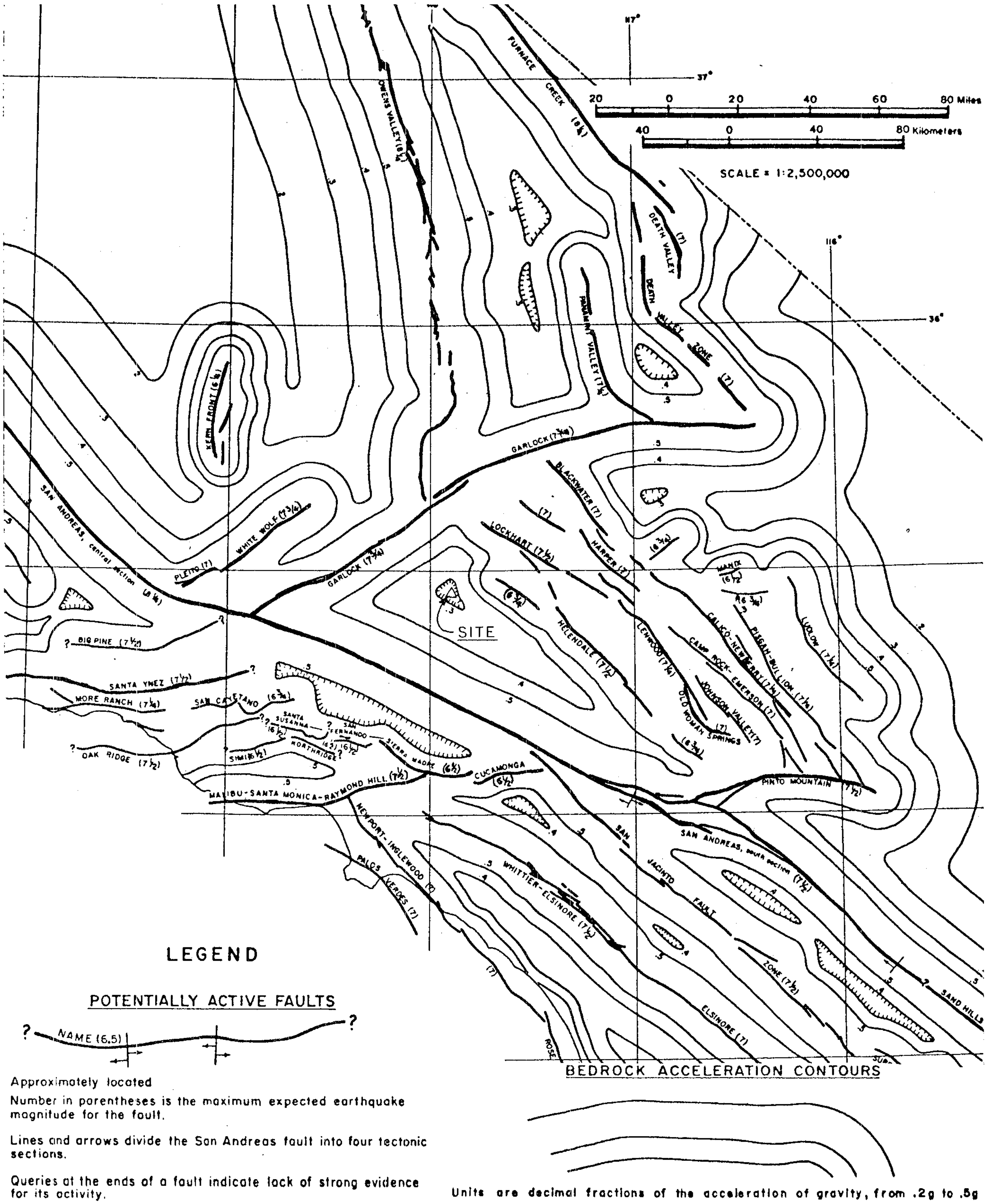
Detailed mapping and trenching projects on the San Andreas (Sieh, 1978) and Garlock (Burke, 1978) faults indicate that the San Andreas has been nearly 10 times as active as the Garlock during the last 14,000 years. Although similar studies have not been carried out on the interior faults, it is likely that activity on any one fault of this group is less than that of the Garlock by at least a similar amount because the relief of stress in the Mojave block is most likely distributed over many faults in this region (Cummings, 1981; Cummings and Leeds, 1977).

2.4 Significant Faults

The general pattern of faults in Southern California is well illustrated in the figures presented in this section. Plates 2.3 and 2.4 show the locations of the better known faults and give an estimate of their maximum credible magnitude seismic events. These faults are detailed in Table 2.1 with the basis of classification indicated in the footnotes. The actual basis for assignment of magnitude is based on Bonilla's (1970) data: the relationship between fault length (length of surface rupture) and earthquake magnitude is depicted in Plate 2.5.



LOCATION OF MAJOR FAULTS IN SOUTHERN CALIFORNIA AND EPICENTERS OF EARTHQUAKES OF MAGNITUDE 6.0 OR GREATER
MONTEREY COUNTY
KINGS COUNTY
TULARE COUNTY
KERN COUNTY
SAN LUIS OBISPO COUNTY
SANTA BARBARA COUNTY
VENTURA COUNTY
LOS ANGELES COUNTY
SAN BERNARDINO COUNTY
ORANGE COUNTY
RIVERSIDE COUNTY
IMPERIAL COUNTY
SAN DIEGO COUNTY
SITE
50 Miles
100 Miles
SAN ANDREAS FAULT
GARLOCK FAULT
WHITE WOLF FLT.
BIG PINE FAULT
PINE MOUNTAIN FLT.
SANTA YNEZ FAULT
SAN GABRIEL FAULT
SIERRA MADRE FAULT ZONE
MALIBU COAST FLT.
NEWPORT-INGLEWOOD FAULT
WHITTIER FAULT
ELSINORE FAULT ZONE
SAN JACINTO FAULT ZONE
IMPERIAL FAULT
SAN CLEMENTE FAULT
CALIFORNIA
MEXICO
SCALE IN MILES
10 0 10 20 30 40 50
LEGEND
Fault along which historic (last 200 years) displacement has occurred.
Quaternary fault displacement (during past 2 million years), without historic (approximately 200 years) record.
1925 (6.3) Epicenter, date and magnitude of pre-1933 earthquakes.
1971 (6.4) Epicenter, date and magnitude of post 1933 earthquakes.
NOTE: 1. Fault traces are indicated by solid lines where well located, by dashed lines where approximately located or inferred, and by dotted lines where concealed by younger rocks or by bays.
2. Fault traces are queried where continuation or existence is uncertain.
3. Pre-Quaternary faults (older than 2 million years) not shown.
4. Epicenter location and magnitude of pre-1933 earthquakes were estimated from historical records and damage reports assigned on Intensity VII (Modified Mercali scale) or greater.
REFERENCES
1. Fault Map of California, California Geologic Data Map Series - Map No. 1, California Division of Mines and Geology, 1975.
2. Hileman, J. A., and others, 1973, Seismicity of Southern California Region, January 1, 1932 to December 31, 1972, Seismological Laboratory, California Institute of Technology, Contribution No. 2385.
3. Map of Major Earthquakes and Recently Active Faults in the Southern California Region compiled by Richard J. Proctor, GEOLOGY, SEISMICITY, and ENVIRONMENTAL IMPACT, Special Publication, Association of Engineering Geologists, October, 1973.
PLATE 2.3



MAXIMUM CREDIBLE ROCK ACCELERATION FROM EARTHQUAKES

Ref: Greensfelder, CDMG MS 23, 1974 PLATE 2.4

Fault	Maximum credible earthquake magnitude	Fault activity rating	References[1]
Owens Valley	8.25	1	
Furnace Creek	8.25	1	Brogan, 1971; Hooke, 1972
San Andreas: "creep" section	7	1, 2, 3	Allen, 1968
Rinconada	7.5	4	Hart, 1969
Death Valley	7	4	Brogan, 1971
Death Valley zone	7	4	Hooke, 1972
Panamint Valley	7.25	4	Proctor, 1973
Kern Front	6.25	4	Proctor, 1973
Garlock	7.75	3, 4	Clark, 1972; Hileman *et al.*, 1973
White Wolf	7.75	1, 3	California Division of Mines, 1955
Pleito	7	4	Crowell, 1968
Big Pine	7.5	1?, 5, 6	Carman, 1964
Santa Ynez	7.5	5, 6	Dibblee, 1966
More Ranch	7.5	2?, 4	Sylvester, 1972
Oakridge	7.5	5, 6	
San Cayetano	6.75	5, 6	
Simi	6.5	4	Wentworth *et al.*, 1973
Northridge Hills	6.5	4	Wentworth *et al.*
Santa Susana	6.5	4	Saul, 1971; Wentworth *et al.*, 1973
San Fernando	6.5	1	Kahle *et al.*, 1971; U.S.G.S., 1971
Sierra Madre	6.5	4	Streitz, 1972; Proctor, 1973
Malibu-Santa Monica-Raymond Hill	7.5	4	Wentworth *et al.*, 1973
Cucamonga	6.5	4	Morton and Yerkes, 1974
San Andreás: central section	8.25	1	Allen, 1968
Pinto Mountain	7.5	4	Proctor, 1973
Helendale	7.5	4	Proctor, 1973
Lockhart	7.5	4	Proctor, 1973
Lenwood	7.25	4	Proctor, 1973
Old Woman Springs	7	4	Proctor, 1973
Johnson Valley	7	4	Proctor, 1973
Camp Rock-Emerson	7	4	Proctor, 1973
Harper	7	4	Proctor, 1973
Blackwater	7	4	Proctor, 1973
Calico-Newberry	7.25	4	Proctor, 1973
Pisgah-Bullion	7.25	4	Proctor, 1973
Manix	6.25	1	Allen, 1965
Ludlow	7.25	4	Proctor, 1973
Other Mojave Desert faults, not named on accompanying map	6.25-7	4	Proctor, 1973
Newport-Inglewood	7	3, 4, 7	Richter, 1958
Whittier-Elsinore	7.5	4	Lamar, 1972; Mann, 1955
San Jacinto zone	7.5	1, 2, 3	Hileman *et al.*, 1971
Laguna Salada	7.25		
Superstition Hills	7	1, 2	Hileman *et al.*, 1971
Imperial	7	1, 2, 3	Hileman *et al.*, 1971
San Andreas: southern section	7.5	1	Hileman *et al.*, 1971
Sand Hills	7.5	6	

[1]General reference: Jennings, 1970

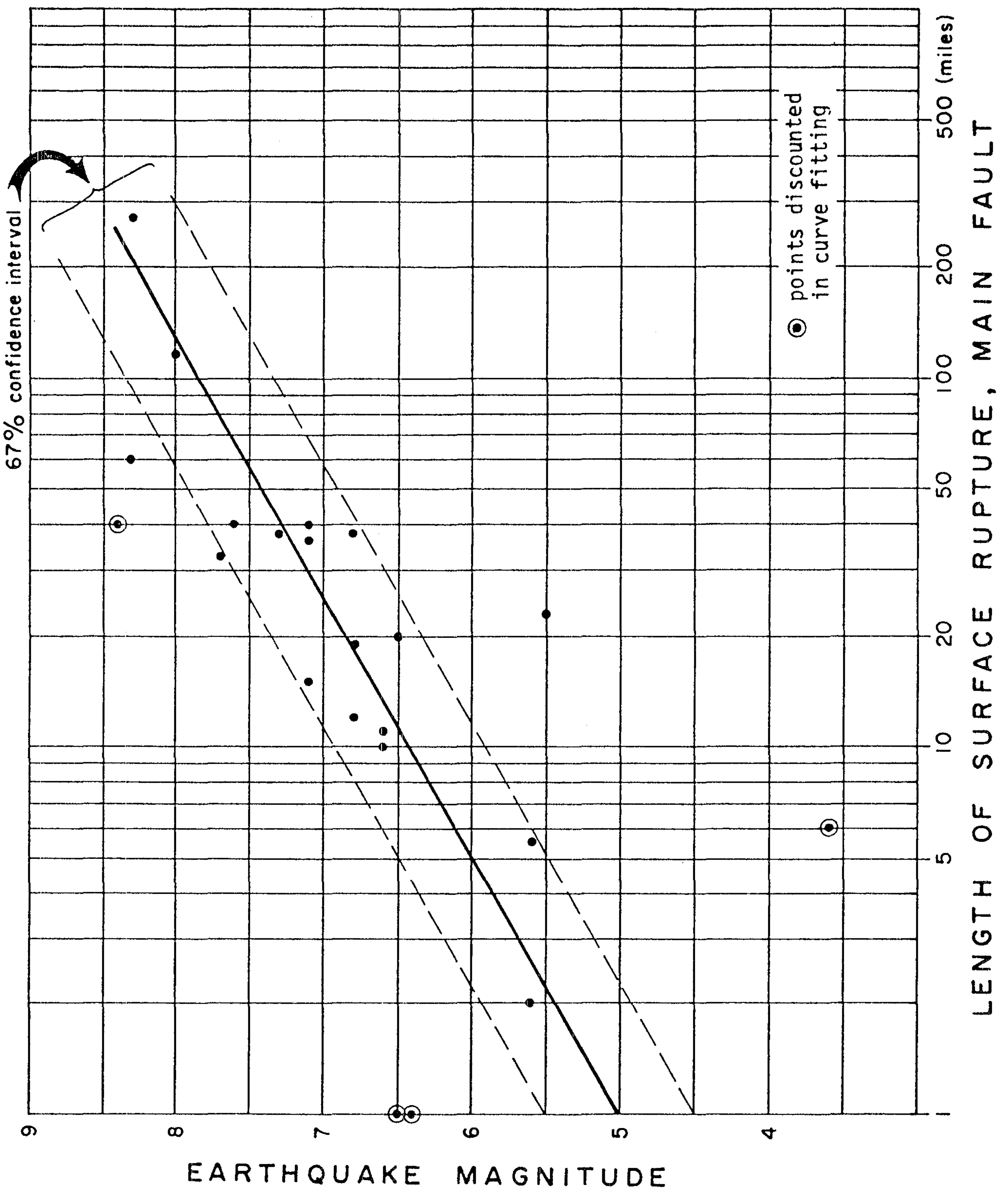
[2]Fault names in quotes are not named in the literature but are assigned here as a matter of convenience.

[3]1 = Surface rupture during a historic earthquake.
2 = Presently occurring creep.
3 = Alignment of earthquake epicenters.
4 = Late Quaternary or Holocene displacement.
5 = Quaternary displacement.
6 = Representative fault in a seismically active tectonic province.
7 = Possible source of a major historic earthquake.

SELECTED ACTIVE AND POTENTIALLY ACTIVE FAULTS

Ref: Greensfelder, CDMG MS 23, 1974

TABLE 2.1



EARTHQUAKE MAGNITUDE VERSUS FAULT RUPTURE LENGTH

Ref: Greensfelder, CDMG MS 23, 1974 (after Bonilla, 1970) PLATE 2.5

Guidance for our own selection of faults and fault characteristics significant to the project was from sources such as Greensfelder (1974), the various County and City Seismic Safety Elements, project reports, Federal and State Geological Surveys, and university publications plus other published and unpublished technical material. An effort was made to be consistent, weighing the recency of the source and the degree of penetration of each study, utilizing personal knowledge, but avoiding personal bias. Where documentation was deemed necessary, reference is made in the text.

There are approximately 75 known historically active, active or potentially active faults within 100 miles of Edwards Air Force Base. Most of these lose significance with regard to the site by being overshadowed by closer, longer or more active faults. The faults that are considered to pose the greatest threat to the site have been grouped as follows: distant faults capable of generating large earthquakes; and nearby faults capable of generating moderate size earthquakes. These faults are discussed in the following sections.

2.4.1 Distant Faults

The major faults in the region that are of significance with regard to shaking at the site are: the San Andreas; the Garlock; the Sierra Nevada; the San Jacinto; the White Wolf; and the San Gabriel. These faults range from 21 to 48 miles in distance from the site. Although there are other major faults in the southern California area they are not considered here because they are either at greater distances from the site or considered to be capable of generating only smaller events than the above listed faults.

As can be seen, the San Andreas fault poses the greatest hazard to the site from the standpoint of accelerations or shaking intensity. This is probably the most documented, instrumented, and studied fault in the world (Allen and others, 1965; Wallace, 1983; Sieh, 1978; Kerr, 1984; and Ross, 1969). Detailed geologic studies of the fault along with historical records of the 1857 earthquake indicate that this fault is likely to generate the largest earthquake of any fault in southern California and that such an event is imminent and will very likely occur during the life of the various structures at the site.

The Garlock fault is somewhat closer to the site than the San Andreas and is also considered to be a major fault. However, it is considered to be less of a hazard owing to the presumption that it will generate lower magnitude earthquakes (Greensfelder, 1974), and that its recurrence rate is less than that of the San Andreas by approximately a magnitude (Burke, 1979). It has not been active historically but abundant geomorphic and geologic evidence indicate that it is active.

The Sierra Nevada fault is a major fault system at the base of the Sierra Nevada range in Owens Valley. One of the largest historic earthquakes in California occurred on it in 1872. This system has also been active in this century north of the 1872 break. The southern portion, nearest to the site, has not been historically active. On the theory that the whole system is equally active and that the southern portion is presently a seismic gap, the next earthquake on this system may occur on this segment (Wallace, 1983).

The San Jacinto fault is presently the most active fault in southern California. It is a major strike-slip fault sub-parallel to the San Andreas system. It has experienced seven or eight earthquakes since 1890, the last being in 1968. None of these events were greater than M=7. This, along with the fact that the San Jacinto is 45 miles from the site relegates it to a much lower hazard classification than the three faults discussed above.

The White Wolf fault is a major reverse type fault 45 miles west of the site. This fault experienced an M≅7.2 earthquake in 1952 resulting in Modified Mercalli intensities at the site of at least VI. The epicenter for this event was over 50 miles from the site. A repeat of this event with a closer epicenter could result in intensities at the site of VII. Hence this fault is considered to present nearly as great a hazard to the site as the San Andreas.

The San Gabriel fault is a large strike-slip fault that diverges from the San Andreas system. This fault is 48 miles from the site. This along with the fact that the maximum probable earthquake on this fault is M=5.5 relegate it to minor significance with regard to the site.

2.4.2 Local Faults

As discussed previously, and shown on Figures 2.1 and 2.3, the Mojave block is cut by numerous northwest-trending faults. Whereas these faults are considerably shorter than the previously discussed group, and hence not capable of generating as large earthquakes, they are much closer to the site (3 to 12 miles). There is a paucity of data on this group of faults although most seem to have some evidence of late-Pleistocene

movement putting them into the potentially active to active category. There have been three earthquakes on faults in this system in the last 40 years that have caused surface displacements (Richter, 1958; Keaton and Keaton, 1977; Fuis, 1976; and Hill and others, 1980). These three faults are over 50 miles from the site, hence are not significant to it, but the Willow Springs-Rosamond fault has yielded fault gouge dated at no older than 5,000 years (D. J. Ponti, oral communication, 1983). This data on a fault only 12 miles from the site (Plate 2.1) suggests that all of these faults should probably be considered to be active unless a detailed examination proves otherwise.

The suite of faults of this grouping that we consider significant to the site are: the Lockhart-Lenwood; the Mirage Valley; the Blake Ranch; the Spring; the Willow Springs-Rosamond; and the Muroc.

2.5 Fault Classification

No universally accepted system exists for the classification of the activity of faults. The present report uses the following classification, which is consistent with others as noted:

HA	Historically Active	Reasonably located and known to have produced earthquakes, or known to be undergoing creep, within the past 200 years. Consistent with AEG*, CDMG, WES, LNG.
A	Active	Evidence of displacement in the Holocene (13,000 years), earthquake epicenters in proximity, strong topographic expression. Consistent with CDMG, LNG.
PA	Potentially Active	Active in Quaternary (2,000,000 years), Quaternary materials offset, groundwater barriers, small earthquake epicenters in proximity, geomorphic expression. Consistent with CDMG, LNG. Equivalent to "Capable" classification of NRC and WES.
I	Inactive	No evidence of movement in Quaternary, or no recognizable offset of Cenozoic materials. Consistent with AEG, CDMG, LNG. WES uses term "Dead" and further states "not seismically active."

*See References (Section 8)

TABLE 2.2

FAULT ACTIVITY

2.6 Fault Rupture

Fault rupture poses a threat to structures that cross active faults. History of actual fault breaks at the ground surface in southern California shows only eleven such breaks (Fig. 2.6). In general, the locations of the surface breaks themselves are largely unpredictable except for those along the largest faults.

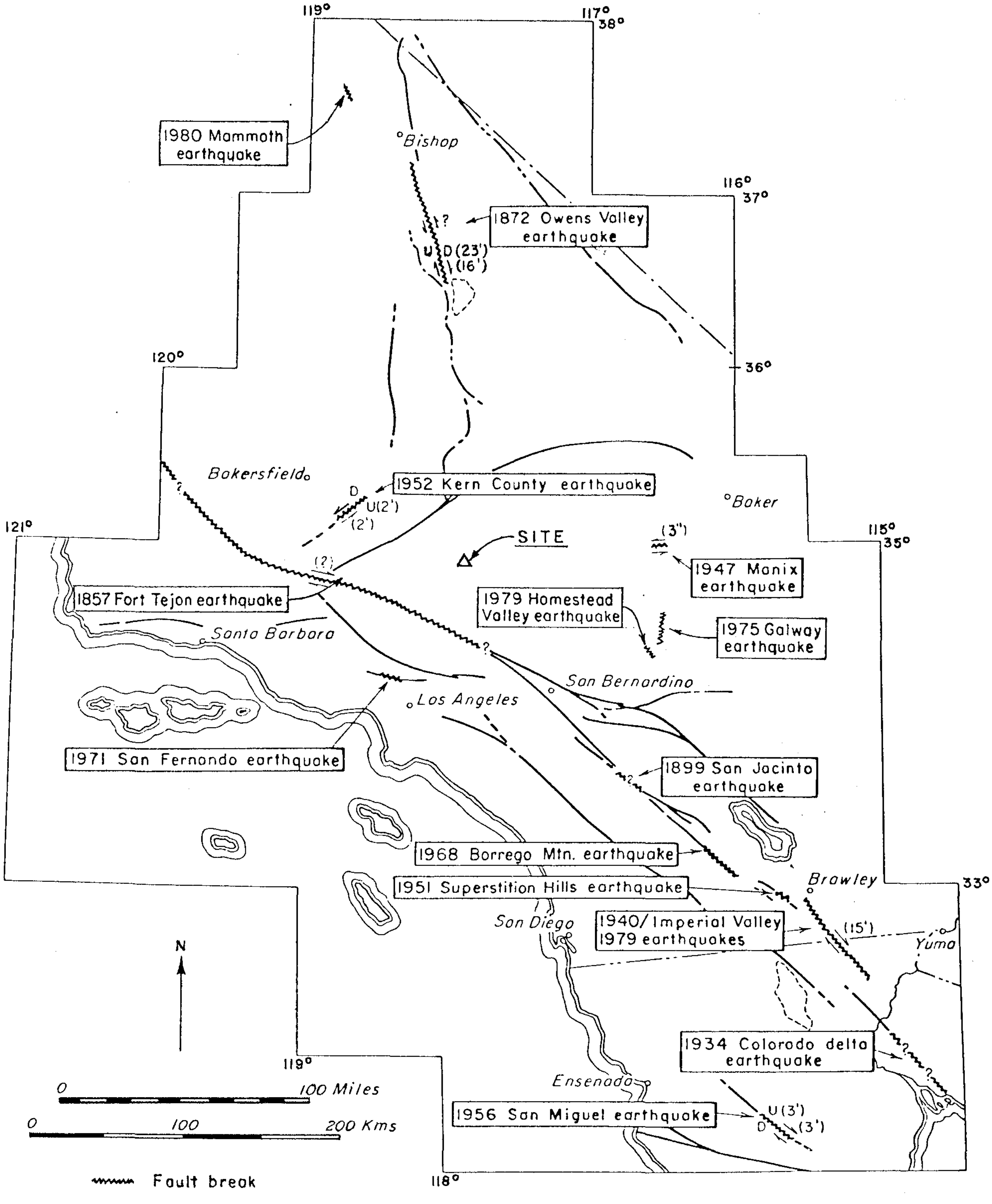
In summary, there are considerably more active and potentially active faults than historic fault ruptures. The latter occurrence is rare but merits consideration, particularly if there are possibly serious consequences of the break.

The likelihood of surface fault rupture at the Edwards Air Force Base NASA Dryden site is considered to be very remote. However, it cannot be dismissed completely because it is not presently known if any buried faults underlie the site which may belong to the group of Mojave block faults. Another, albeit low, risk is the possibility of sympathetic movement, including fault rupture extending to the ground surface, of these possible underlying faults in response to large motions from a great earthquake on the San Andreas fault.

2.7 Potential for Site Ground Rupture

Because of the minimal amount of alluvium (2 to 7 feet) overlying the crystalline rock beneath the Computer Center site, and the absence of groundwater, the likelihood of liquefaction or lurching occurring in these materials is considered to be remote.

Although no faults are known or shown on reviewed maps to cross the site, the possibility exists, as suggested by seismic activity, that certain of the small nearby faults may continue subsurface toward the site.



HISTORIC FAULT BREAKS

(SOUTHERN CALIFORNIA REGION)

PLATE 2.6

Allen et al, 1965
Updated 1984

3. SEISMOLOGY

3.1 General

The seismicity of the southern California region is illustrated in the tabulations and plots of several researchers, varying in both time span and lower level of sensitivity. It is considered necessary to examine the region through these different windows to observe the sources of the larger events and local activity of the smaller events.

Plate 2.3 shows the location of major faults and epicenters of earthquakes of magnitude 6.0 or greater for the past two centuries. The locations of the larger events can be seen to be associated with the major faults of the region.

Bedrock acceleration associated with major faults is indicated in Plate 2.4. A listing of these selected active and potentially active faults is shown in Table 2.1.

Earthquake magnitude versus fault rupture length is depicted in Plate 2.5.

The potential for ground motion at the site from earthquakes generated on the various faults is given in Table 3.1.

The seismic parameters of magnitude and intensity (MM 31) are defined in Appendix B.

POTENTIAL GROUND MOTION FROM SIGNIFICANT FAULTS

Fault	Dist. to Site (mi)	Activity Rate	Max. Credible Earthquake				Max. Probable Earthquake			
			At Epicenter		At Site		At Epicenter		At Site	
			Magnitude	Int MM31	Int MM31	Accel g *	Magnitude	Int MM31	Int MM31	Accel g *
MAJOR REGIONAL FAULTS										
San Andreas	29	HA	8.5	XII	XI	0.40	8.25	XII	IX	0.40
Garlock	21	A	7.75	X	IX	0.40	7.0	VIII	VI	0.25
Sierra Nevada (south end)	25	A	8.5	XII	IX	0.40	7.5	IX	VII	0.25
San Jacinto	45	HA	7.75	X	VII	0.30	6.5	IX	IV	0.15
White Wolf	45	HA	7.75	X	VII	0.30	7.25	IX	VII	0.30
San Gabriel	48	PA	6.5	IX	IV	0.15	5.5	VI	III	0.10
MOJAVE BLOCK FAULTS										
Lockhart-Lenwood	20	A	7.5	X	VIII	0.40	6.5	IX	V	0.20
Mirage Valley	9	A	6.5	IX	VII	0.30	5.5	VI	V	0.20
Blake Ranch	12	A	6.75	IX	VI	0.25	5.5	VI	V	0.20
Spring	12	A	6.75	IX	VI	0.25	5.5	VI	V	0.20
Willow Spring-Rosamond	12	A	6.5	IX	VI	0.25	5.5	VI	V	0.20
Muroc	3.5	A	6.5	IX	IX	0.40	5.5	VI	VI	0.25

Note: Maximum Credible Earthquake (MCE) and Maximum Probable Earthquake (MPE) parameters are selected on the basis of pertinent published and unpublished literature, thoroughness of study of the source area, historical activity, fault length/magnitude relationships, fault mechanics, site geometry, and bias of our staff seismologists/geologists. In simple terms, the MPE event is postulated to occur during the project lifetime and should be considered an "operational" event. The MCE is potentially possible but unlikely during the project lifetime.

HA = Historically active fault; A = Active fault; PA = Potentially active fault.

*Acceleration at base rock. Values are average of 3 largest peaks.

TABLE 3.1

3.2 Historical Seismicity

Earthquakes have been chronicled in California since the arrival of the first Spaniards. Mission records have been used for the early period; and systematic instrumental recorded dates from the early days of the University of California in Berkeley (1888). A continuous instrumental California record has been maintained since that time. Southern California was a bit slower--beginning its instrumental record in 1932 with Carnegie funding and, more recently, with support of the U. S. Geological Survey. This activity is centered at the California Institute of Technology in Pasadena. Summary publication of coherent data has been the contribution of the State (California Division of Mines and Geology) and the Federal government (currently the U. S. Geological Survey). Tables 3.2 and 3.3 summarize the larger seismic events of interest, both historical and instrumental.

A plot of earthquake epicenters near the NASA Dryden facility (Plate 3.1) shows all events of magnitude 4.0 and greater for the period 1900 through 1983. Although published with data through 1974, it has been updated through July 1983 with USGS data.

Another pair of plots, Plate 3.2, shows this area with events of magnitude 3.0 and above (1932 through 1983), and a plot of the smaller western Mojave block area with all events for the same time span regardless of magnitude. Note that Plate 3.1 (magnitude 4.0 and above) shows a blank for the area; Plate 3.2 shows <u>some</u> events with magnitudes of 3.0 or greater and <u>many</u> events when the smallest instrumentally recorded activity is plotted.

A plot of all events is also shown, Plate 3.3, enlarged to match the scale of Plate 2.3. Thus, an overlay of Plate 3.3 on Plate 2.3 indicates a low level of seismicity at the site, associated with the named and unnamed faults.

EARTHQUAKES OF SOUTHERN CALIFORNIA - HISTORIC

DATE	INTENSITY	MAGNITUDE	LOCATION
1769 Jul 28	VIII-X	7.5	Olive
1852 Oct 26	---	8.0	North Los Angeles County
1852 Nov 9	IX	---	Imperial Valley
1852 Nov 27-30	---	8.0	North Los Angeles County
1857 Jan 9	XI	7.7	Fort Tejon
1872 Mar 26	---	7.7	Owens Valley
1906 Apr 18	IX	---	Imperial Valley

EARTHQUAKES OF SOUTHERN CALIFORNIA - HISTORIC

TABLE 3.2

EARTHQUAKES OF SOUTHERN CALIFORNIA - 1912-1984

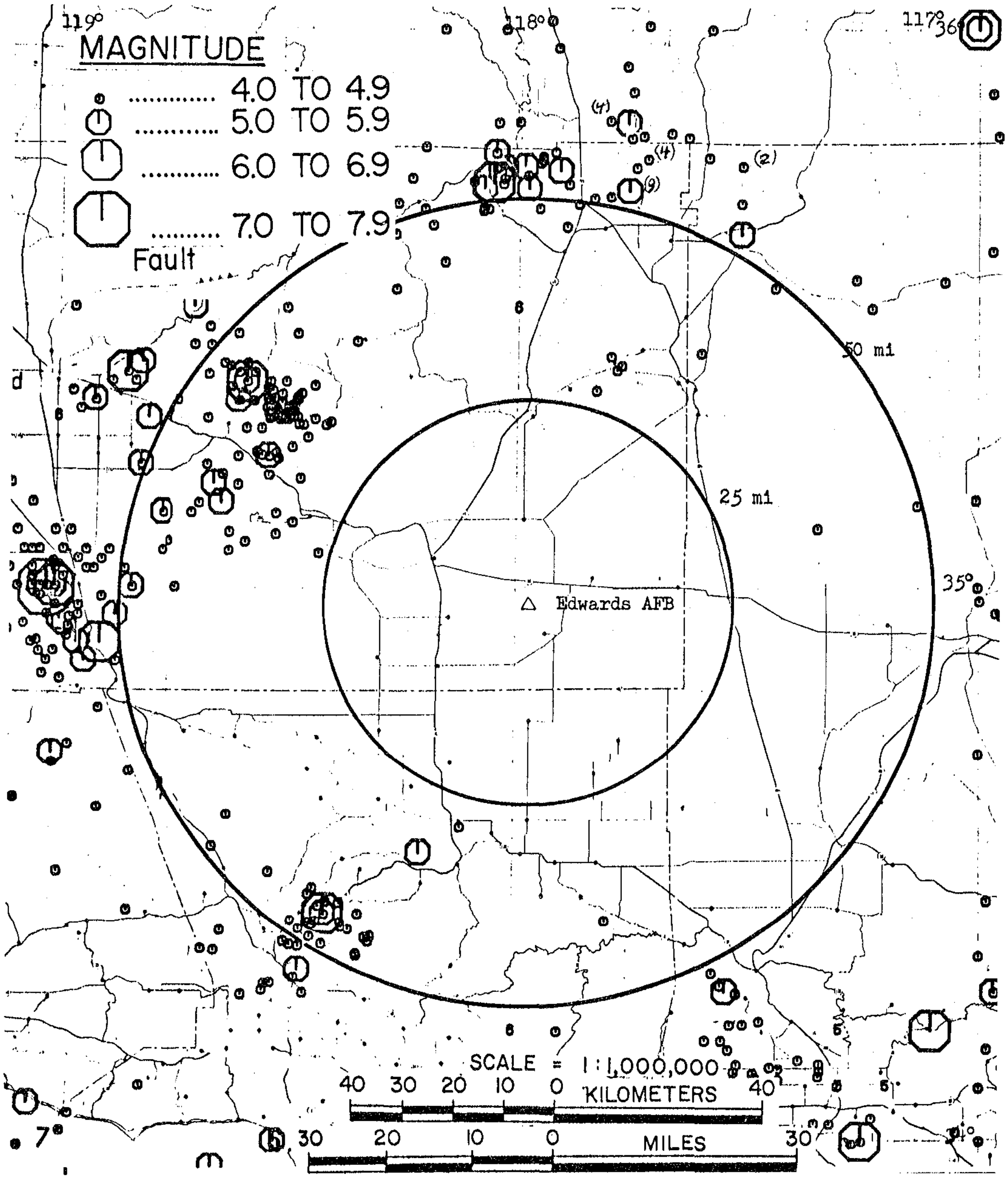
MAGNITUDES 6.0 AND GREATER

DATE	TIME (PST)	LAT.	LONG.	MAG.	INT.	FELT AREA	LOCATION
1915 Jun 22	19:59	32.8	115.5	6.25	VIII	50,000-100,000	Imperial Valley
1915 Jun 22	20:56	32.8	115.5	6.25	VIII	50,000-100,000	Imperial Valley
1915 Nov 20	16:14	32	115	7.1	VII	120,000	Colorado Delta
1916 Oct 22	18:44	34.9	118.9	6	VII	25,000-50,000	Tejon Pass
1918 Apr 21	14:32	33.7	117	6.8	IX	130,000	San Jacinto
1923 Jul 22	23:30	34	117.2	6.25	VII	70,000	San Bernardino
1925 Jun 29	06:42	34.3	119.8	6.3	VIII-IX	--	Santa Barbara
1927 Sep 17	18:07	37.5	118.7	6	VII	75,000	Bishop
1933 Mar 10	17:54	33.6	118.0	6.3	IX	100,000	Long Beach
1934 Dec 30	05:52	32.2	115.5	6.5	IX	60,000	Colorado Delta
1934 Dec 31	10:45	32	114.7	7.1*	X	80,000	Colorado Delta
1935 Feb 24	--	32.0	115.2	6.0	--	--	Colorado Delta
1937 Mar 25	08:49	33.5	116.6	6.0	VII	30,000	Terwilliger Valley
1940 May 18	20:36	32.7	115.5	7.1*	X	60,000+	Imperial Valley
1940 Dec 8	--	31.7	115.1	6.0	--	--	Colorado Delta
1941 Jun 30	23:51	34.4	119.6	6.0	VIII	20,000	Santa Barbara
1942 Oct 21	08:22	33.0	116.0	6.5	VII	35,000	Borrego Valley
1946 Mar 15	05:49	35.7	118.1	6.3	VIII	65,000	Walker Pass
1947 Apr 10	07:58	35.0	116.6	6.2*	VII	75,000	Manix
1948 Dec 4	15:43	39.9	116.4	6.5	VII	65,000	Desert Hot Springs
1952 Jul 21	03:52	35.0	119.0	7.7*	XI	160,000	Kern County
1952 Jul 22	23:53	35.0	118.8	6.4	VII	--	Kern County
1952 Jul 23	05:17	35.2	118.8	6.1	VII	--	Kern County
1952 Jul 28	23:03	35.4	118.9	6.1	VII	--	Kern County
1954 Mar 19	01:54	33.3	116.2	6.2	VI	40,000	Santa Rosa Mountains
1954 Oct 24	--	31.5	116.0	6.0	--	--	Agua Blanca
1954 Nov 12	04:26	31.5	116	6.3	V+	--	Agua Blanca
1956 Feb 9	06:32	31.8	115.9	6.8	VI+	30,000+	San Miguel
1956 Feb 9	--	31.7	115.9	6.1	--	--	San Miguel
1956 Feb 14	10:33	31.5	115.9	6.3	V+	--	San Miguel
1956 Feb 14	17:20	31.5	115.9	6.4	V+	--	San Miguel
1966 Aug 7	09:36	31.8	114.5	6.3	VI	--	Gulf, California
1968 Apr 8	18:29	33.1	116.1	6.5*	--	--	Borrego Mountains
1971 Feb 9	06:01	34.4	118.4	6.6*	XI	80,000	San Fernando
1979 Oct 15	16:17	32.6	115.3	6.6*	X	60,000+	Imperial County
1980 May 25-27	--	37.6	118.8	6.3*	VIII	100,000	Mammoth Lakes
1980 Jun 8	20:28	32.27	114.95	6.3	--	--	Western Arizona
1983 May 2	16:42	36.22	120.32	6.3*	VIII	--	Coalinga

*Surface faulting.

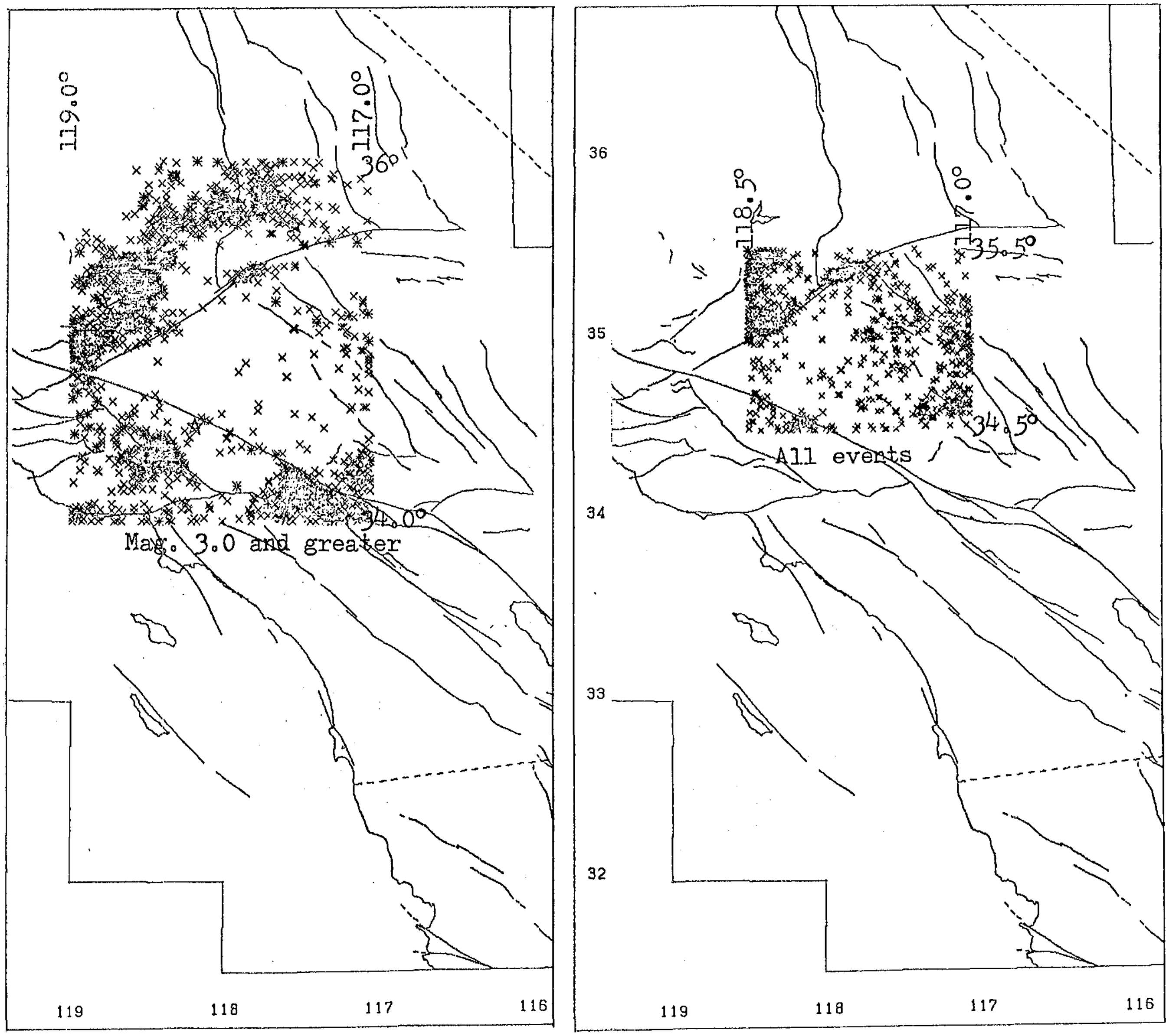
EARTHQUAKES OF SOUTHERN CALIFORNIA - 1912-1984

TABLE 3.3

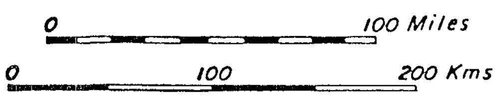


EARTHQUAKES EPICENTERS NEAR EDWARDS AFB
Magnitude 4.0 and Greater. 1900 through July 1983

Ref: CDMG MS39, Updated. PLATE 3.1



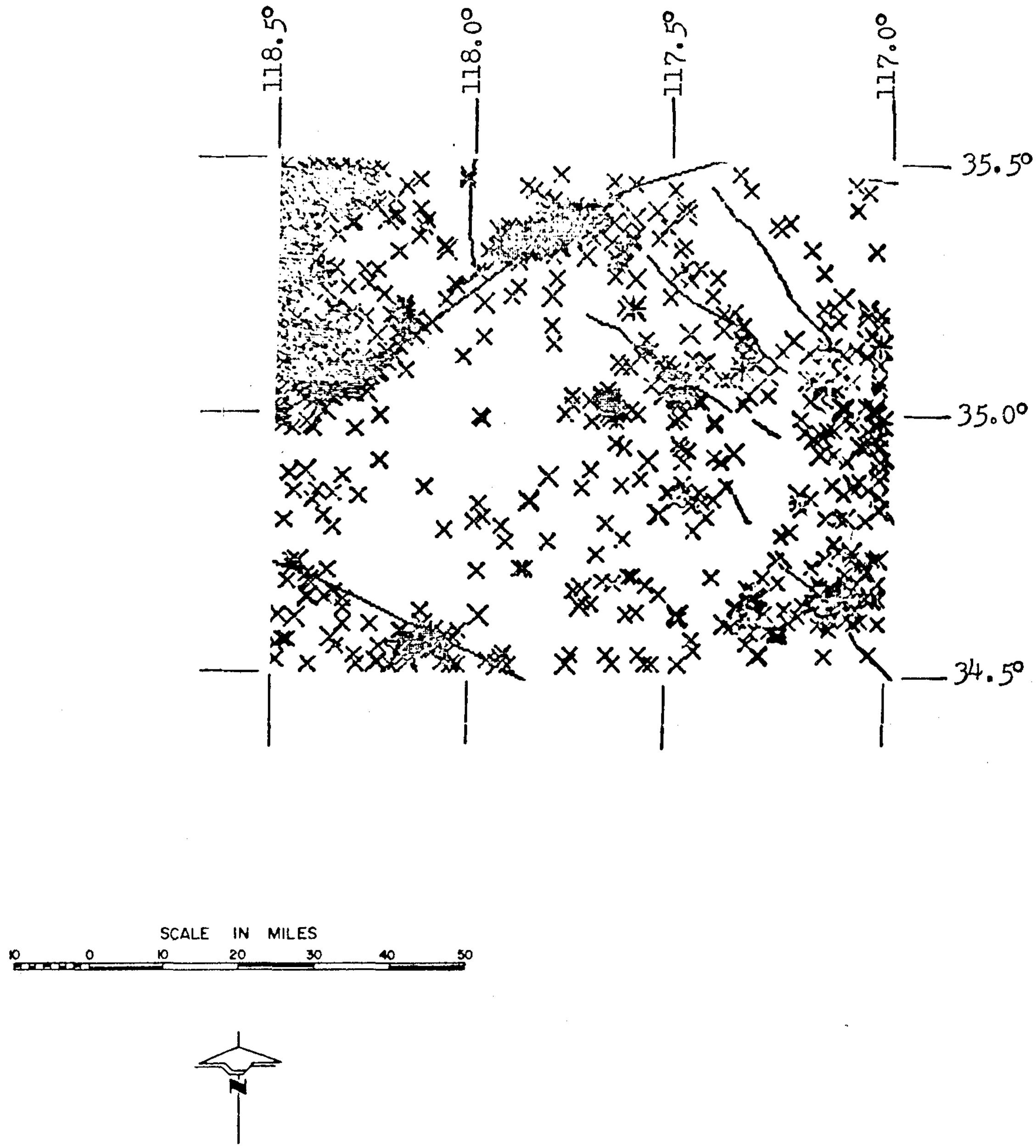
× ML < 3.0
× 3.0 ≤ ML < 4.0
✳ 4.0 ≤ ML < 5.0
✯ 5.0 ≤ ML < 6.0
✯ ML ≥ 6.0



EARTHQUAKE EPICENTERS NEAR EDWARDS AFB
Magnitude 3.0 & Greater, and All Events. 1932 through 1983

Ref: CIT 1984

PLATE 3.2



EARTHQUAKE EPICENTERS NEAR EDWARDS AFB
All Events, 1932 through 1983

Ref: CIT 1984

PLATE 3.3

3.3 Significant Earthquakes

An epicenter count of earthquakes within a 25 mile, 50 mile, and 100 mile radius of the NASA Dryden facility for the periods indicated yields the following results:

Magnitude	Radius - miles 25	50	100	Period of Observation
Less than 3.0	*	--	--	1974-1983
3.0 to 3.9	0	--	--	1932-1983
4.0 to 4.9	0	120	510	1900-1983
5.0 to 5.9	0	12	80	1900-1983
6.0 to 6.9	0	2	15	1900-1983
7.0 or greater	0	0	1	1769-1983

The wider, 100 mile sweep includes the epicenter of the 1952 magnitude 7.2 Kern County earthquake. The two 6+ magnitude events, each about 45 miles from the site, are the 1971 San Fernando earthquake and an aftershock of the Kern County 1952 sequence.

Note that the 50 and 100 mile totals include events within the smaller circles and the areas are each four times the size of the next smaller circle. Thus, if seismicity were uniform, the 50 miles radius column should list four times as many events as the 25 miles column, and the 100 mile column 16 times as many.

The lack of reported macroseismic activity near the site is apparent from these numbers. It is even further highlighted by examination of activity within the entire western Mojave block (Plate 3.1). For this purpose, the block is defined as the region between the San Andreas and the Garlock faults west

*Slightly less than one shock per year with magnitude less than 3.0. However, some of these may be quarry or mining blasts.

of about 50 miles east of the NASA Dryden facility. There are limitations on the data. It is believed to be complete for magnitude 4 events since the turn of the century, magnitude 3 since 1932, and magnitude 2.4 since 1974. Many smaller magnitude events are contained in the data and are included in our examination. Some may be spurious, and some are quarry or mining blasts that have not been edited out of the data.

The single magnitude 4.4 shock within the block was recorded October 11, 1966 at 35.106°N, 117.346°W, 37 miles east-northeast of the site. This is the only magnitude 4.0 or larger event within the block for the period 1900-1983. It is the only event within the range 3.0 or larger recorded for the period 1932-1983. However, small events with magnitudes less than 3.0 have been recorded at a rate of approximately four per year in this same period (1932-1983). As indicated, some of these may be spurious or quarry blasts. This phase of the investigation bears further study. One of these small events occurred practically on site October 14, 1942 with a magnitude of 2.5 at 35.0°N, 118.0°W. The quality of the determination was not good, fixed at ±15 km of the location noted.

The larger events are distant from the site and along known faults, such as the 1952 Kern County earthquake to the northwest and 1971 San Fernando earthquake to the southwest, and their associated aftershocks. These are the largest events within the past century to affect the site; statistically, their many aftershocks account for a large portion of the seismic activity. The 1852 and 1857 earthquakes, although outside the time span considered, were undoubtedly more significant to the site.

It should be borne in mind that epicentral determinations are imprecise, particularly on the smaller and older events. The circle of error probability is seldom noted but can vary from a few kilometers for the well located events to as much as 0.5^{0} for the older, noninstrumentally recorded events. The quality of epicentral determination has increased dramatically over the past years, especially in this area, with the support of the U. S. Geological Survey. The definition of epicenter should also be remembered, i.e., that point on the surface of the earth that lies above the hypocenter (first starting break along the fault plane surface, at depth). The epicenter is not the center of energy release; the hypocenter is merely the starting point of the fault rupture on its plane.

3.5 Recurrence

Recurrence of seismic activity along the several capable nearby faults has been studied, and a range of recurrence rates published. There is an overwhelming opinion among seismologists and geologists that have studied the area that a very large magnitude earthquake on the San Andreas fault is imminent. That could mean one week, one month, or 10 years, but certainly in the foreseeable future. Specific return periods along the San Andreas vary from 80 to 160 years. Since there has not been a major San Andreas event in Southern California in over a century, the consensus is that the fault is ready to "let go."

The "favored" section for a San Andreas break is the reach between San Bernardino to the west of Taft. Since the break will probably be at least 250 miles long, this places the nearest San Andreas energy source 29 miles southwest of the site, with a recurrence period that is moot. The event is so long overdue, and indications so ominous, that consideration of a recurrence period

is an unnecessary exercise. The event must be considered short-term. The only question at the moment is when. The magnitude should be the same as other great San Andreas events, 8+. A 50 percent probability within 5 years has been stated.

Recurrence of the 1952 Kern County event is difficult to assess. That event was large, magnitude 7.2, and the location unexpected. There is some indication that its recurrence rate is 150 years or more. An epicenter on the White Wolf fault at about 45 miles lessens the impact upon the site.

The unusual lack of events that might have an effect on the site makes any averaging of activity meaningless. The nearby segment of the San Andreas has been inactive for more than a century; the nearby segment of the Garlock has had no events as large as magnitude 4.0; events within the Mojave block are all 50 miles or more east of the site; the western Mojave block is almost aseismic. These factors control the selection of design events but preclude meaningful statistical seismicity.

In summary, a great San Andreas magnitude 8+ event is imminent; local nearby events would be unexpected but could be magnitude 4.5 to 5.5.

4. SEISMIC CRITERIA

4.1 Methodology

Seismic criteria for the NASA Dryden facility site at Edwards Air Force Base have been developed by using a multistep method, as follows:

1. Definition of seismic zones, faults, or source areas
2. Development or selection of site or region specific attenuation characteristics.
3. Calculation of site ground motions (acceleration, velocity, displacement, and duration)
4. Selection of analogous time-histories and response spectra, along with their scale factors.

4.2 Seismic Source Areas

The site is exposed to seismic ground motion from earthquakes originating in three principal source areas:

Source I — San Andreas Fault Zone - A source of great historical seismic activity. The recurrence of magnitude 8+ event along this fault at its nearest approach to the site (29 miles) is postulated as a design event.

Source II — Mojave Block Fault Group - The occurrence of a moderate magnitude event nearby is a remote possibility despite the historic absence of events larger than magnitude 4.4.

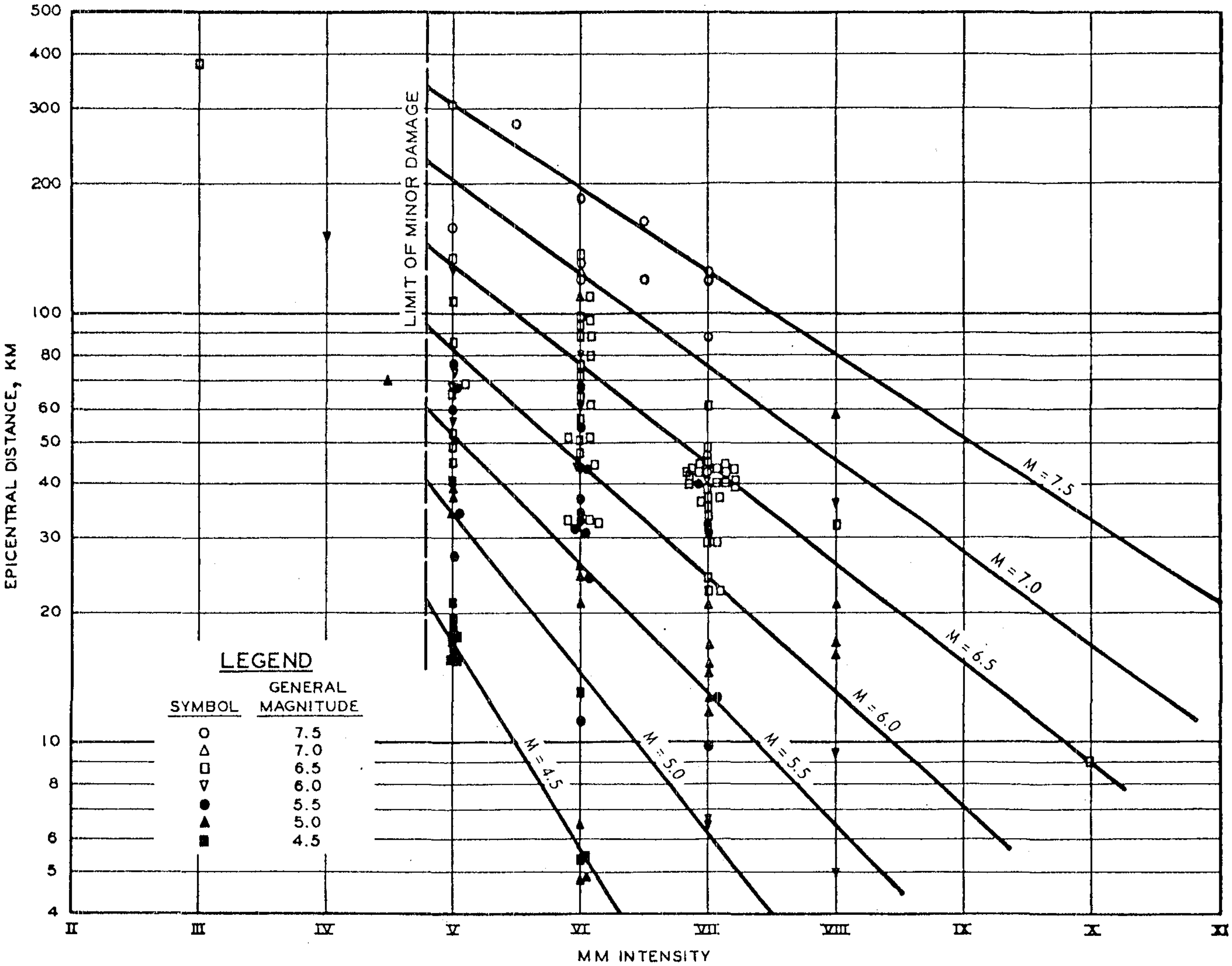
Source III — The effect of the more distant or less active faults is enveloped in the two above design events, or source areas.

4.3 Attenuation

Site ground motion can be determined by attenuating maximum epicentral source region ground motion to the appropriate distance. A number of attenuation curves have been developed from worldwide and regional studies of isoseismal maps. Data from western United States earthquakes have been plotted by Krinitzsky and Chang, 1975 (Plate 4.1) relating intensity to distance for a range of earthquake magnitudes. Note the very wide scatter of the data. Acceleration is related to distance in an unpublished study by Krinitzsky and Marcuson, 1982 (Plates 4.2 and 4.3). Note that the data for these studies are for hard sites only, with ground conditions similar to those found at the NASA Dryden site. These studies and isoseismal maps for the larger regional earthquakes of southern and central California provide an excellent data set for determining attenuation characteristics in the Mojave area.

4.4 Ground Motion

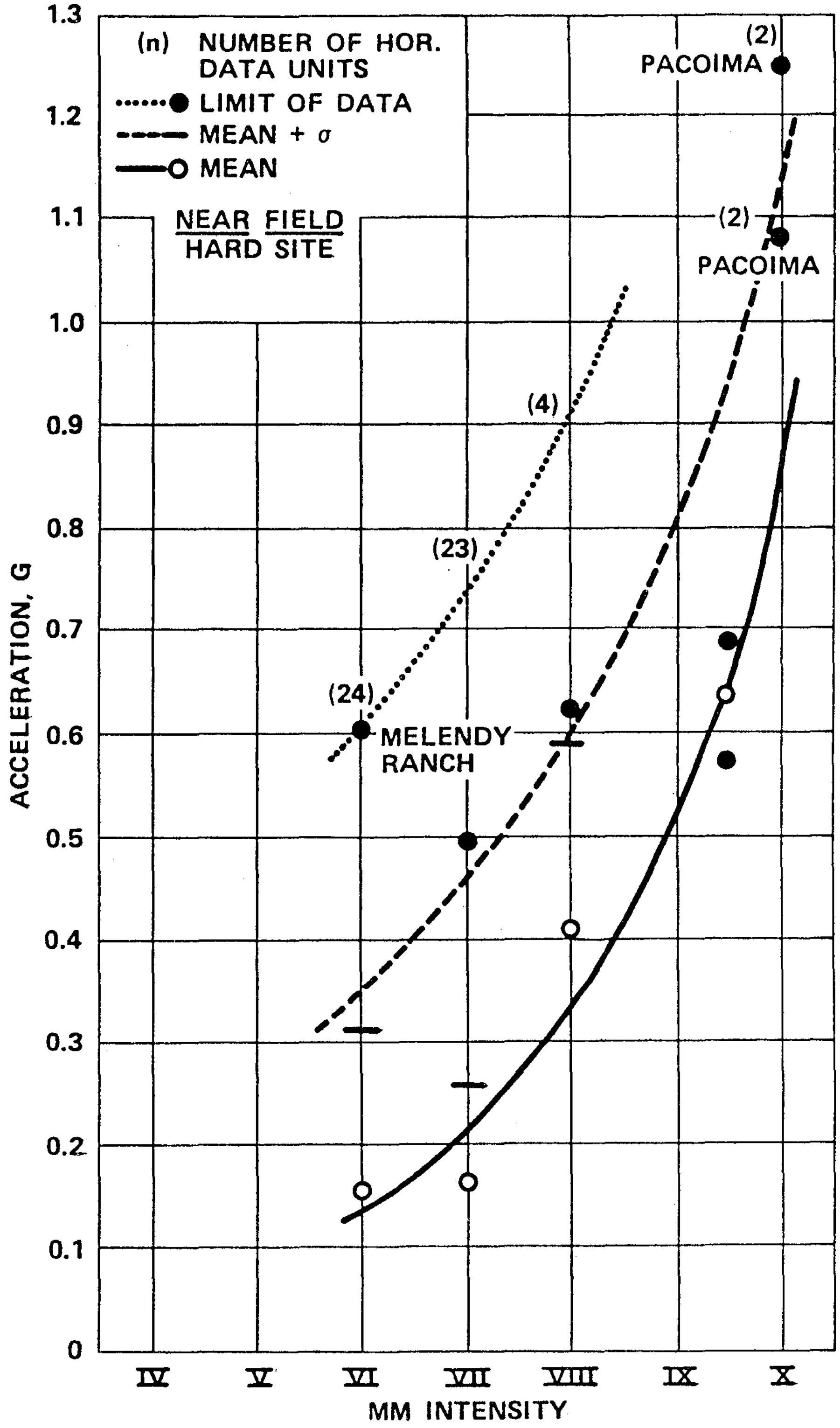
Site ground motion is calculated from the attenuation characteristics given above. Extrapolation to the larger San Andreas event has been calculated. Representative ground motions that may be experienced at the NASA Dryden site are indicated in Table 4.1.



INTENSITY VERSUS MAGNITUDE AND EPICENTRAL DISTANCE

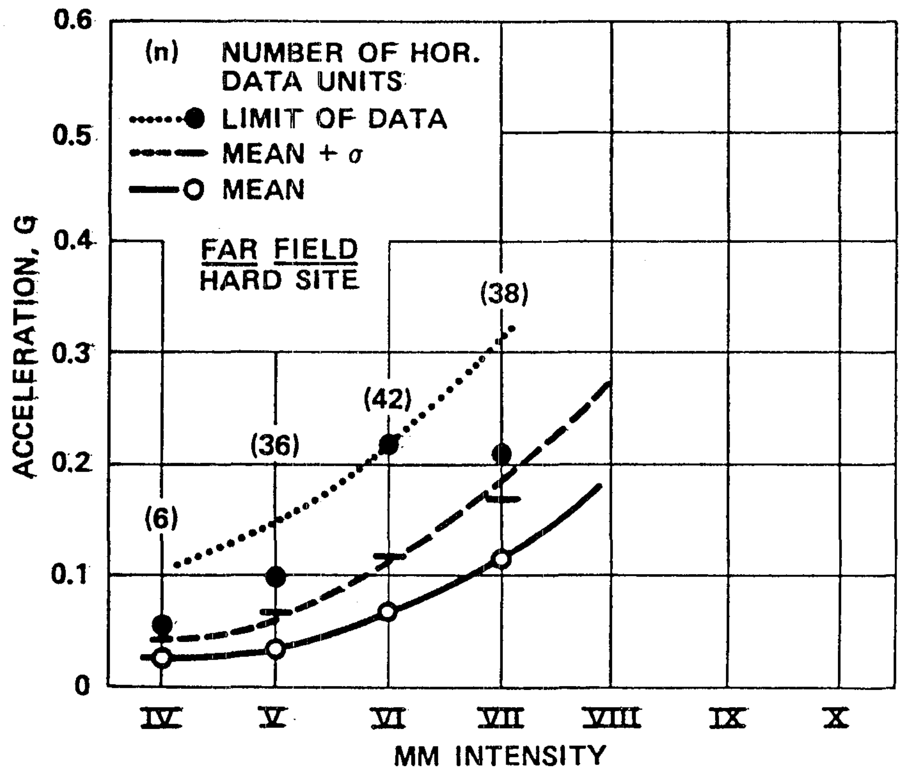
Ref: Krinitzsky and Chang, 1975

PLATE 4.1



ACCELERATION VERSUS MM INTENSITY
NEAR FIELD--HARD SITE

Ref: Krinitzsky & Marcuson, Nov. 1982 PLATE 4.2



ACCELERATION VERSUS MM INTENSITY

FAR FIELD--HARD SITE

Ref: Krinitzsky & Marcuson. Nov. 1982 PLATE 4.3

TABLE 4.1

REPRESENTATIVE GROUND MOTIONS AT NASA EDWARDS FACILITY

Source	Mag	Int I_0	Distance to Site (mi.)	I_{site}	Accel, g	Veloc, cm/sec	Disp, cm	Bracketed Duration at 0.05g sec.	Predominant Period, sec.
I: San Andreas	8+	XII	29	IX	0.40	50	25	40	0.5
II: Mojave Block	4.5	VI	3.5	VI	0.20	20	10	6	0.20

The basis for selection of the representative ground motion at the site is as much intuitive, or art, as science. The Maximum Probable Earthquake is one that has a high likelihood of taking place during the lifetime of the project. It is usually at least a repeat of the largest historical event and is tempered by the evaluation of the Maximum Credible Earthquake the system will support. In nuclear facility terms, it is the Operating Basis Event--and is designed to provide design level adequate to ensure life safety. In very seismically active areas of California, the MPE may approach the MCE. That is, an event larger than 8+ on the San Andreas is remote, the effects of which would only lengthen the disturbed area but not increase radiation normal to the fault. Certain of the faults appear more active along midsections than at their terminals. Other faults appear to have all the potential for movement but do not have a demonstrated historic activity. Consideration is principally given to historic activity and fault length. The work of other researchers and design values for similar projects are also factors, as is the magnitude-intensity-acceleration relationship.

Thus, the selection process takes these and many other factors into consideration. The figures given in Table 4.1 are meant to be reasonable, biased toward the MCE, but with an admitted moderate degree of the expectation of exceedance. Also, they are meant to represent several repeated excursions at periods of interest and not a single high frequency spike.

The data summaries of Krinitzsky, Chang, and Marcuson have provided much guidance for the ground motions selected. The values are for firm soil or southern California rock, such as exists at the site.

5. DESIGN ACCELEROGRAMS

Selection of analogous accelerograms for the design earthquake is usually an unsatisfying process. Accelerograms selected should be analogous for the design earthquake with respect to magnitude, depth of focus, earthquake mechanism, intervening structural geology, lithology of path, and site characteristics. In addition, there should be several records. Most of the models fail to meet these criteria in most categories.

No good time-history accelerogram exists for a great earthquake at moderate distance. The best available is the N21E component of the Taft record of the 1952 Kern County earthquake. Its 7.2 magnitude is the largest event in the 51 year old inventory. Unfortunately, it fails because of its location on a deep alluvial column. (See Appendix C for site data, accelerogram, and response spectra). However, it does offer guidance with respect to spectral shape and duration. The Taft site is 27 miles from the epicenter of the 1952 earthquake and slightly closer to the trace of the White Wolf Fault. Consideration must be given in its use to the slightly longer periods present.

A scale factor of 2.62 would be required to bring the N21E trace up to the recommended design acceleration; therefore, there is a deficiency in amplitude as well as spectral content. Spectral content should also be modified by tightening the time base by about 20%, thus raising the spectral response at shorter periods.

The selection of analogous accelerograms for this design earthquake has been simplified for the nearby event because of the simplicity of the site itself. There is but a very thin (7 to 10 feet) cover of soil or disintegrated granite. It is known that the foundations of the structure penetrate the surficial material and that the structure is founded on crystalline rock. Hence, it is a true "hard" site, a situation not usual for southern California.

"Hard" site accelerograms have traditionally been limited to records written at Helena, Montana and at Golden Gate Park, San Francisco. Moreover, there are but two useful accelerograms from those stations, written in 1935 and 1957, respectively. In addition, several of the sites to the north of the 1971 San Fernando epicenter are considered to be on rock. Also, the recent expansion of the network of instruments developed in the northern Sierra by the California Division of Mines and Geology has produced a number or records of ground motion on rock.

The magnitude 6.0 Helena, Montana 1935 accelerogram was recorded on an instrument founded on Precambrian limestone located at Carroll College, an epicentral distance of 4 miles. The station has since been moved to another location. The peak acceleration was measured as 0.146g on the N-S component and 0.145 on the E-W component. Peak vertical acceleration was 0.089 g. Appendix C shows station location, geology, acceleration, and response spectra.

The magnitude 5.3 San Francisco 1957 earthquake developed only 0.102 g at the Golden Gate Park site, located on weathered Franciscan radiolarian chert and interbedded shale. The station is about 5 miles from the San Andreas, along which the earthquake was located. The record was examined but not used in this investigation because of its small amplitude.

The inventory of accelerograms written near NASA Dryden site was also considered. There are 32 accelerograph stations in the region bounded by 34.5°N and 117.0° to 118.5°W. However, many of these stations have been recently installed, so only five of the stations have produced usable records with accelerations of 0.10g or greater. All five of these records, with maximum accelerations from 0.13 to 0.19g, were of the 1971 San Fernando earthquake:

Station No.	Name	Peak g	Site Conditions
121	Fairmont Reservoir	0.17	17'± sand & gravel, over granite
125	Lake Hughes No. 1	0.17	80+' alluvial over granite
126	Lake Hughes No. 4	0.19	15' decomposed granite, over bedrock
262	Palmdale Fire Station	0.13	---
585	Pearblossom Pumping Plant	0.15	---

Station location, geology, accelerograms, and spectra are shown in Appendix C for the Fairmont Reservoir, Lake Hughes No. 1, and Lake Hughes No. 4 sites.

Recent "rock" records are available from the Mammoth Lakes earthquakes of May 1980 written on a central recording system at a tunnel location in Long Valley Dam. The geology is described as layered blocky rhyolite with flows 2 to 15 feet thick. The

tunnel is within the flows. The surface has 3 feet of soil and 10 feet of weathered rhyolite. The records fail as analogies. Three sets of data yield as many different responses. In addition, site geometry and earthquake mechanism do not correspond to the Edwards site.

A summary of accelerograph data is given in Table 5.1.

TABLE 5.1

ACCELEROGRAM DATA

Location	Date	Dist to Fault, mi	Mag	Peak Accel, g	Site Conditions	Shown in Appendix
Taft	1952	27	7.7	0.18	Deep alluvium	Yes
Helena	1935	4	6.0	0.146	Pre-C limestone	Yes
Golden Gate Park	1957	5	5.3	0.102	Franciscan	No
Fairmont Reservoir	1971	21.6	6.4	0.17	15' to granite	Yes
Lake Hughes No. 1	1971	19.5	6.4	0.17	80' to granite	Yes
Lake Hughes No. 4	1971	18	6.4	0.19	15' to granite	Yes
Long Valley Dam Tunnel	5-27 1980	14.1	6.3	0.24	Rhyolite flows	No

6. RECOMMENDATIONS FOR SEISMIC DESIGN CRITERIA

On the basis of the study, it is recommended that the NASA Edwards Air Force Base Facility be evaluated for its resistance to the two earthquakes postulated in this report:

1. A magnitude 8.5 event on the nearest approach of the San Andreas Fault, 29 miles, would impose an acceleration of 0.40g on the site with a bracketed duration of 40 seconds. It is suggested that a scaled trace of the N21E component of the Taft accelerogram of the 1952 Kern County earthquake is an adequate model.

2. A near-field magnitude 4.5 event from a Mojave block fault would impose an acceleration of 0.20g at the site with a short bracketed duration of 6 seconds. It is suggested that the unscaled trace of the Lake Hughes No. 4 S69E component from the San Fernando Valley earthquake of 1971 be used as an appropriate model.

7. RECOMMENDATIONS FOR FUTURE STUDIES

A comparison of the microseismic activity of the western portion of the Mojave block with the known faults in this area suggests a casual relationship between some of the faults and some of the seismicity. However, seismicity near the project site suggests the possibility that additional faults, not presently known, exist beneath or near the NASA Dryden Facility. The existence of such a fault would not be expected to significantly alter the seismic characteristics recommended in this report for nearby earthquakes. What would be affected is the possibility of surface rupture occurring somewhere on the site other than at the Data Center site.

Therefore, it is recommended that to determine the safety of other sites on the facility from such an occurrence, the following work be carried out:

1. Review and interpretation of aerial photographs of the area in possession of the Air Force and other governmental agencies.
2. Obtaining, review and interpretation of EROS remote sensing data and aerial photographs of the area.
3. Review in detail all seismic records of the area and plot at sufficient scale to compare with fault maps.
4. Surface mapping to determine details of local geology and faults found on above imagery and fault maps.
5. Possible trenching of nearby faults determined to be significant in the preceding steps.
6. Possible installation of seismometer and recording of local microseismicity to better define location of local seismic events and source areas.

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APPENDICES

A. PLOT PLAN AND BORING LOGS

B. SEISMIC SCALES

1. Intensity
2. Magnitude

C. ACCELEROGRAMS, SPECTRA, AND SITE GEOLOGY

Taft, 1952

Helena, Montana, 1935

Fairmont Reservoir, 1971

Lake Hughes No. 1, 1971

Lake Hughes No. 4, 1971

Long Valley Dam, 1980

APPENDIX A

PLOT PLAN AND BORING LOGS

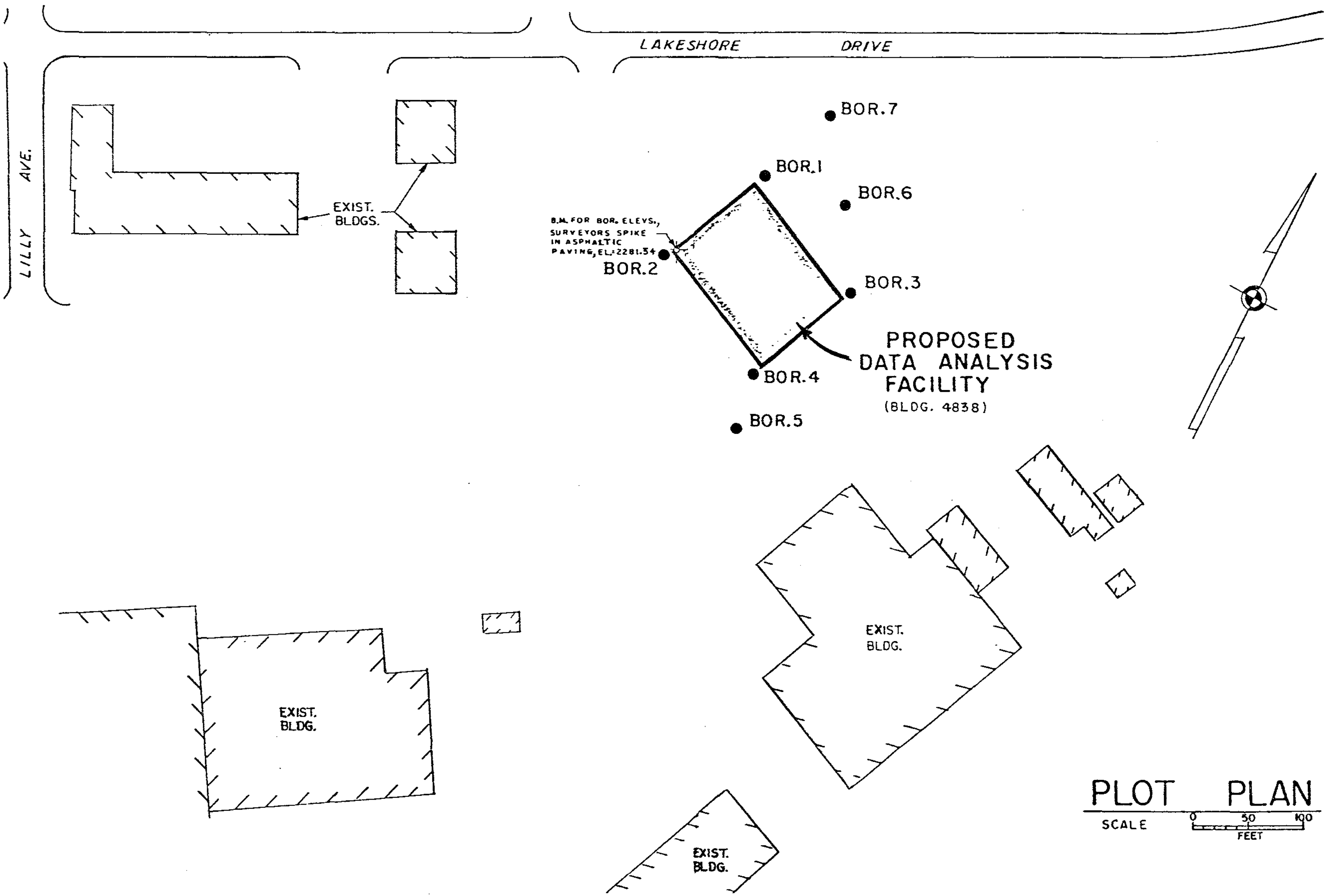

LAKESHORE DRIVE
LILLY AVE.
EXIST. BLDGS.
BOR.7
BOR.1
BOR.6
B.M. FOR BOR. ELEVS., SURVEYORS SPIKE IN ASPHALTIC PAVING, EL.=2281.54
BOR.2
BOR.3
PROPOSED DATA ANALYSIS FACILITY
(BLDG. 4838)
BOR.4
BOR.5
EXIST. BLDG.
EXIST. BLDG.
EXIST. BLDG.
PLOT PLAN
SCALE
0
50
100
FEET

PLATE A-1

BORING I

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2281.5*

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.		DESCRIPTION
							SM	SILTY SAND - fine, lenses of Clayey Silt, light brown to grey
2280			7.1	131	23	▮		GRANITE - weathered, decomposed, light grey to grey
			7.7	114	26	▮		
	5							
			6.2	128	41	▮		
2275								
			5.8	137	57	▮		
								Light grey and white
	10							
			2.3	120	59	▮		
2270								
	15		3.6	140	54	▮		

NOTE: Water not encountered. No caving.

* Elevations refer to datum of reference drawing; see Plate 1 for location and elevation of bench mark.

PLATE A-2

BORING 2

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2281.5

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.
			5.1	126	5	
2280						
			11.8	107	13	
	5		6.8	131	25	
2275			6.6	141	49	
	10		2.8	135	115	
2270						
	15					

SM — 1½" Asphaltic Paving

FILL - SILTY SAND - fine, some gravel, light brown

SM — SILTY SAND - fine, light brown

GRANITE - weathered, decomposed, light grey and grey

(BORING TERMINATED DUE TO DIFFICULT DRILLING IN GRANITE)

NOTE: Water not encountered. No caving.

PLATE A-3

BORING 3

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2279.7

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.
			3.2	118	13	■
			4.3	106	56	■
2275	5					
			4.5	-	79	■
			1.1	-	197	■
2270	10					
2265	15					

SM SILTY SAND - fine, few gravel, light grey and light brown

GRANITE - highly weathered, decomposed, light grey to grey

(BORING TERMINATED DUE TO DIFFICULT DRILLING IN GRANITE)

NOTE: Water not encountered. No caving.

PLATE A-4

BORING 4

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2279.2

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.
			12.9	107	16	
2275			7.3	122	25	
	5					
			2.6	133	34	
			5.3	142	41	
2270						
	10					
			2.9	128	66	
2265						
	15					

SP ML — 2" Asphaltic Paving

FILL - SAND and SILT - some gravel, browr

SM — SILTY SAND - fine, light brown

GRANITE - weathered, decomposed, light grey and grey

White

(BORING TERMINATED DUE TO DIFFICULT DRILLING IN GRANITE)

NOTE: Water not encountered. No caving.

PLATE A-5

BORING 5

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2278.9

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.
			5.6	116	23	
2275						
	5		1.4	110	82	
2270						
	10					
2265						
	15					

SM

2" Asphaltic Paving
SILTY SAND - fine, light brown

GRANITE - weathered, decomposed, light grey to grey
(BORING TERMINATED DUE TO DIFFICULT DRILLING IN GRANITE)

NOTE: Water not encountered. No caving.

PLATE A-6

BORING 6

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2280.6

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.		
2280							SM	SILTY SAND - fine, light brown
			4.3	118	55			GRANITE - weathered, decomposed, light grey to grey
			1.3	135	148			
2275	5							NOTE: Water not encountered. No caving.
2270	10							
	15							

PLATE A-7

BORING 7

DATE DRILLED: September 2, 1981

EQUIPMENT USED: 24"-Diameter Bucket

ELEVATION: 2282.0

ELEVATION (ft.)	DEPTH (ft.)	"N" VALUE STD. PEN. TEST	MOISTURE (% of dry wt.)	DRY DENSITY (lbs./cu. ft.)	DRIVE ENERGY (ft. kip/ft.)	SAMPLE LOC.
2280			3.3	122	25	■
			2.6	131	72	■
	5					
2275						
	10					
2270						
	15					

SM SILTY SAND - fine, brown

GRANITE - weathered, decomposed, light grey and grey

NOTE: Water not encountered. No caving.

PLATE A-8

APPENDIX B

SEISMIC SCALES

1. INTENSITY
2. MAGNITUDE

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX-Rossi-Forel Scale.)

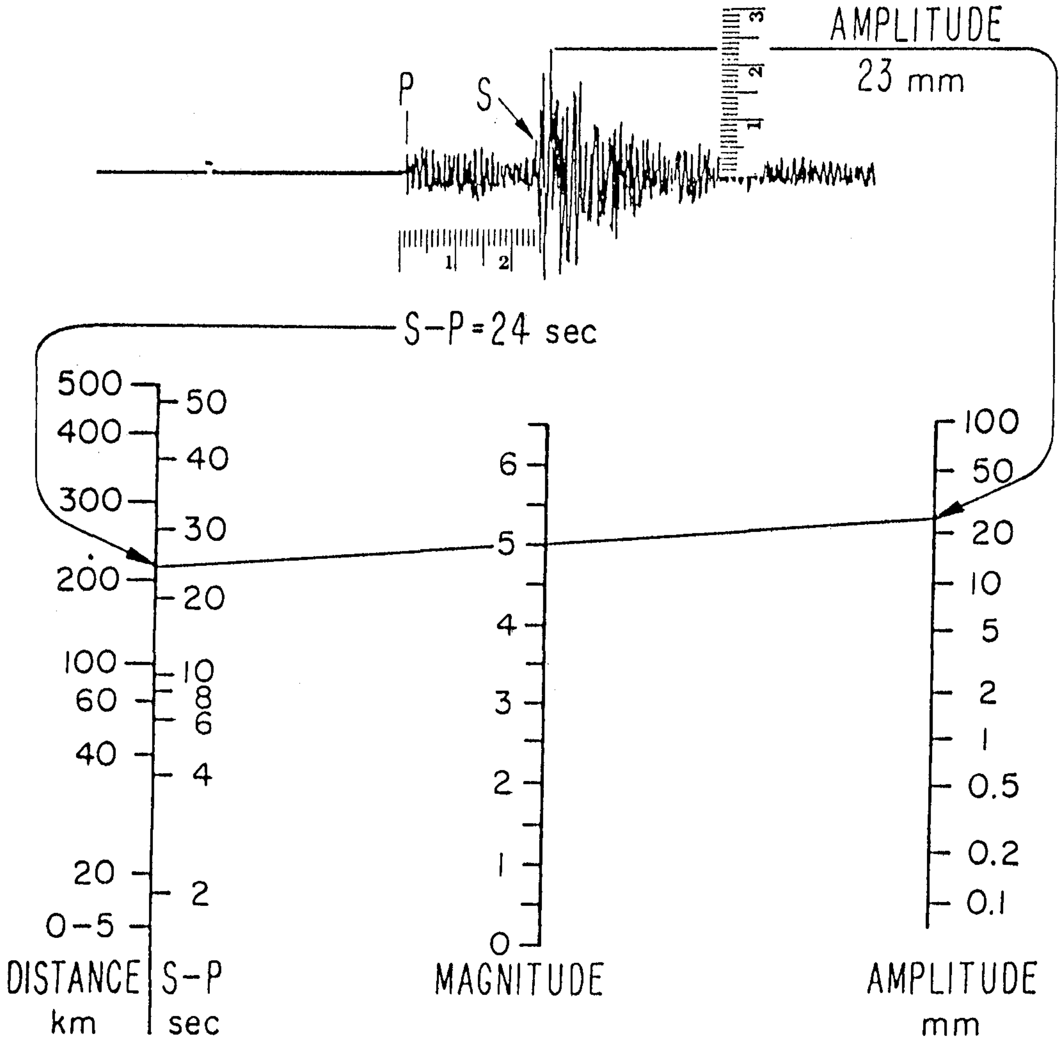
IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air.

PLATE B-1



TO DETERMINE THE MAGNITUDE OF AN EARTHQUAKE WE CONNECT ON THE CHART

A. THE MAXIMUM AMPLITUDE RECORDED BY A STANDARD SEISMOMETER, AND
B. THE DISTANCE OF THAT SEISMOMETER FROM THE EPICENTER OF THE EARTHQUAKE (OR THE DIFFERENCE IN THE TIMES OF ARRIVAL OF THE P AND S WAVES)

BY A STRAIGHT LINE, WHICH CROSSES THE CENTER SCALE AT THE MAGNITUDE.

RICHTER MAGNITUDE SCALE NOMOGRAPH

PLATE B-2

The Magnitude Scale is a means of indicating the size on an earthquake on the basis of instrumental records.

Dr. C.F. Richter, Seismological Laboratory, California Institute of Technology, developed a magnitude scale which is based on the maximum recorded amplitude of a standard seismograph located at a distance of 100 km from the source of a shallow earthquake. The magnitude is defined by the relationship :

$$M = \log A - \log A_o$$

In this relationship, A is the recorded trace amplitude for a given earthquake at a given distance written by a standard instrument, and A_o is the trace amplitude for a particular earthquake selected as a standard. The zero of the scale is arbitrarily fixed to fit the smallest recorded earthquakes. The largest known earthquake magnitudes are on the order of 8 3/4. This magnitude is the result of observations and not an arbitrary scaling. The upper magnitude limit is not known, but is estimated to be about 9.

Empirical relationships between earthquake magnitude and energy release have been developed by several investigators. There is no exact relationship between earthquake magnitude and energy for large earthquakes, and these empirical relationships should be considered no more than approximations.

RICHTER EARTHQUAKE MAGNITUDE SCALE

Ref: Richter, Elementary Seismology, 1958

PLATE B-3

APPENDIX C

ACCELEROGRAMS, SPECTRA, AND SITE GEOLOGY

Taft, 1952

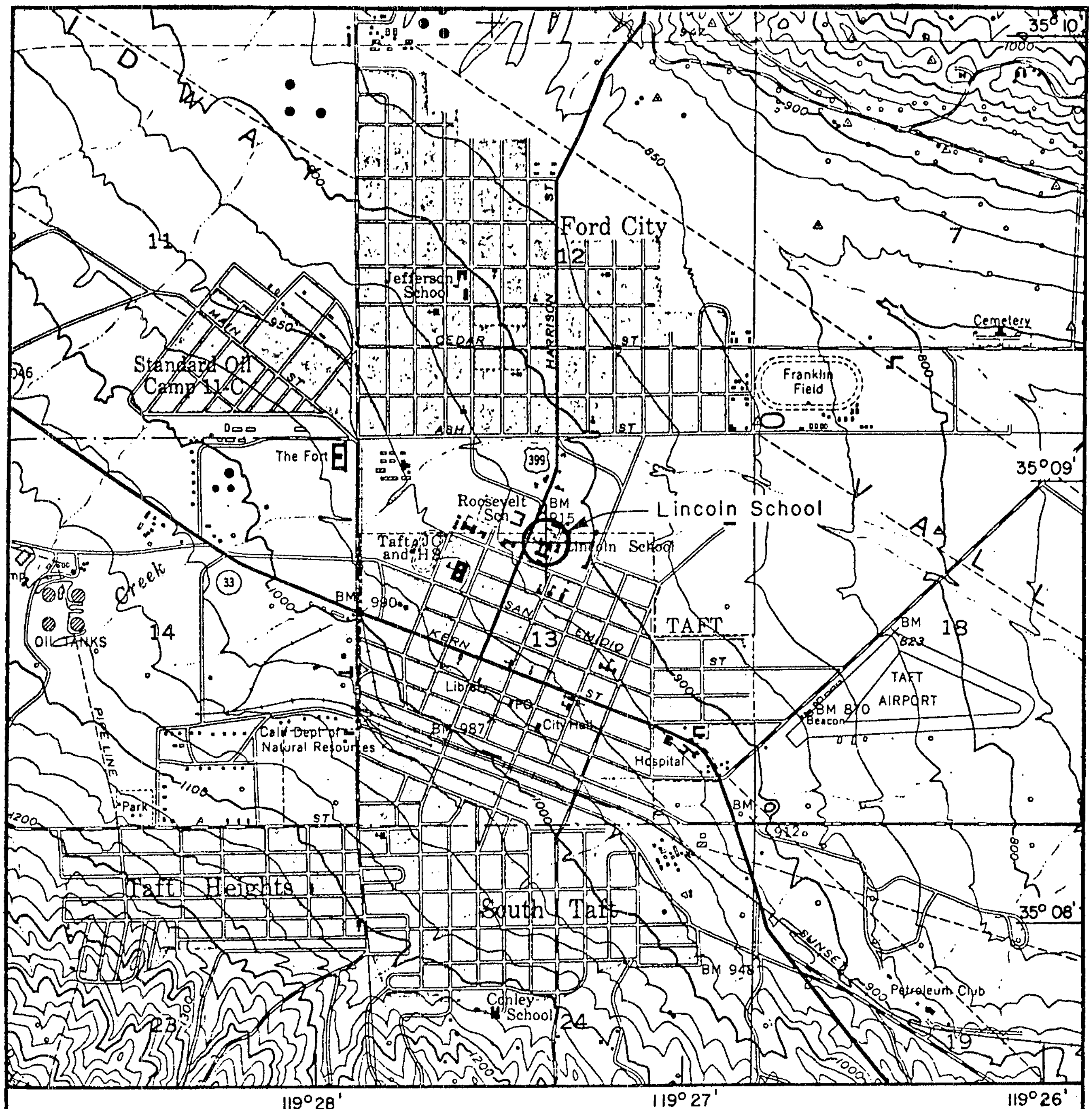
Helena, Montana, 1935

Fairmont Reservoir, 1971

Lake Hughes No. 1, 1971

Lake Hughes No. 4, 1971

Long Valley Dam, 1980



0 1000 2000 4000

Scale in feet

N

Taft; Lincoln School

USGS Topographic Quadrangle:
Taft, California

Coordinates: 35° 08' 52" N
119° 27' 22" W

Location: Sixth and Warren Streets.

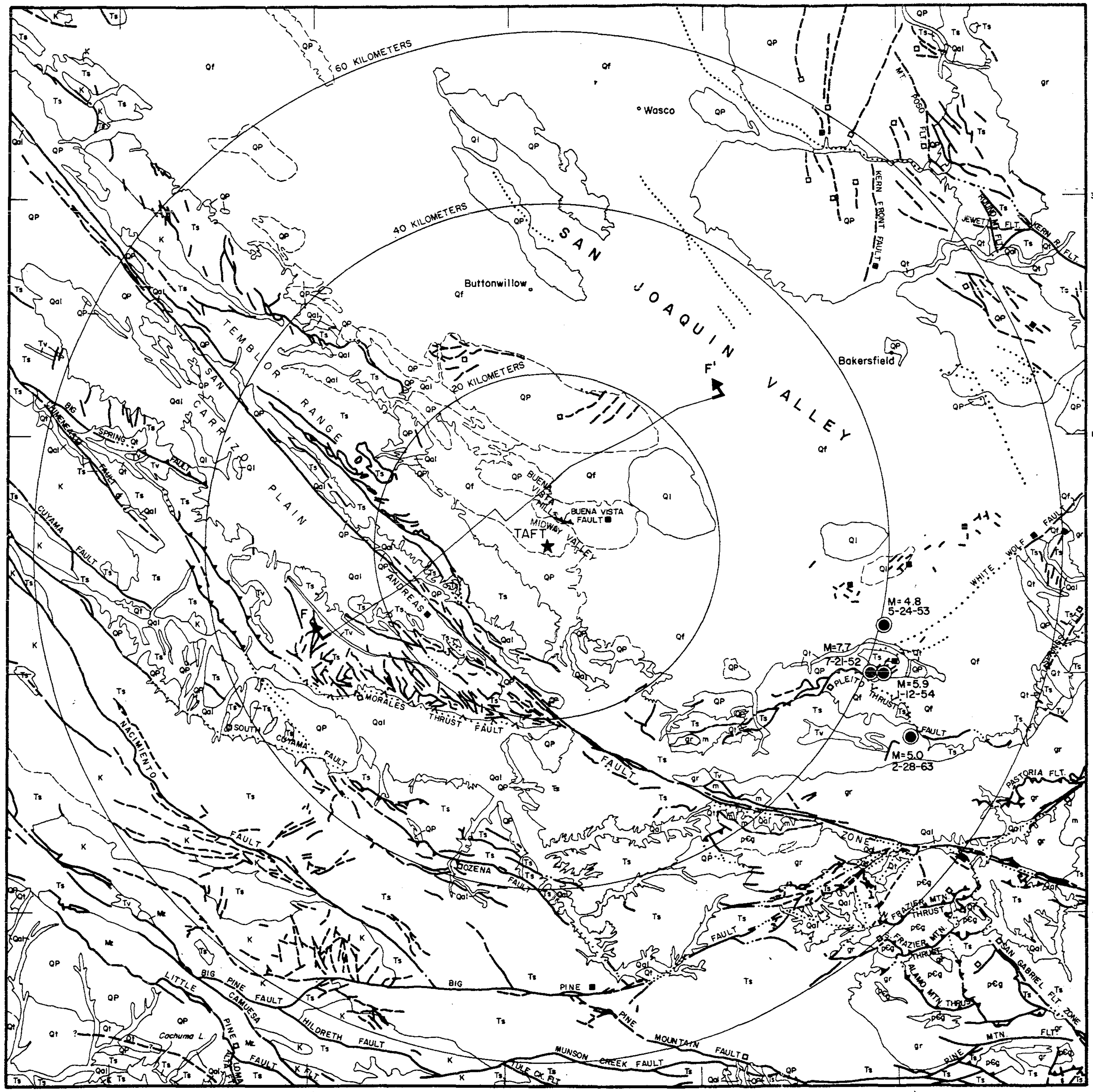
Structure: Two-story, reinforced concrete

Note: Coordinates scaled from USGS topographic quadrangle

STATION LOCATION PLAN
LINCOLN SCHOOL
TAFT
PLATE C-1

LOCATION, TAFT ACCELEROGRAPH
Ref: NUREG/0029, Vol.2

PLATE C-1



Location of Geologic Map

EXPLANATION

- Qal — Alluvium, Recent in age; includes dune deposits.
- Qf — Stream channel, fan, and basin deposits, Recent in age.
- Ql — Lake deposits, Quaternary in age.
- Qt — Marine deposits, marine and nonmarine terrace deposits, Quaternary in age; includes upper Pliocene marine deposits.
- QP — Nonmarine sedimentary-deposits, Plio-Pleistocene in age.
- Tv — Volcanic rocks and igneous intrusive rocks, Tertiary in age.
- Ts — Sedimentary rocks, Tertiary in age.
- K — Sedimentary rocks, Cretaceous in age.
- Mz — Mesozoic sedimentary rocks; also includes metamorphic rocks.
- gr — Mesozoic granitic rocks; also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks.
- m — Metamorphic and metasedimentary rocks, pre-Cretaceous in age
- P — Sedimentary and volcanic rocks, Paleozoic in age.
- p-Cg — Precambrian igneous and metamorphic rocks; includes crystalline rocks which may be as young as Mesozoic.

- ★ Seismograph Station location.
- M=5.7 6-5-60 Epicenter location, Richter magnitude, and date of occurrence.
- □ Faults that have moved during Quaternary time without historic record (approx. past 2 million years).
- ■ Faults that have moved during historic time (approx. 200 years).
- Contact — Dashed where approximately located.
- Fault — Dashed where approximately located, dotted where concealed, queried where existence is uncertain.
- Thrust Fault — Barbs on upper plate, dashed where approximately located, dotted where concealed.
- Cross-section location, section F-F' shown on Fig. 6-5.

NOTES:

1) Geology is simplified from Jennings and Strand (1969), Smith (1964), Jennings (1959), and Jennings (1958). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1973).

2) Information on fault activity (Quaternary activity, Historic activity) is from Jennings (1973). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1973, for details).

3) Individual faults within the San Andreas fault zone show evidence of Quaternary and Historic activity. (See Jennings, 1973, for details).

4) Heavy border on boxes indicates units that appear on this figure.

5) Earthquake magnitudes and epicentral locations are from United States Department of Commerce (1955, 1959, 1965), and Hudson and others (1971a, 1972a, 1973a, 1974a, 1975a).

0 5 10 15
Scale in miles

0 5 10 15 20
Scale in kilometers

N

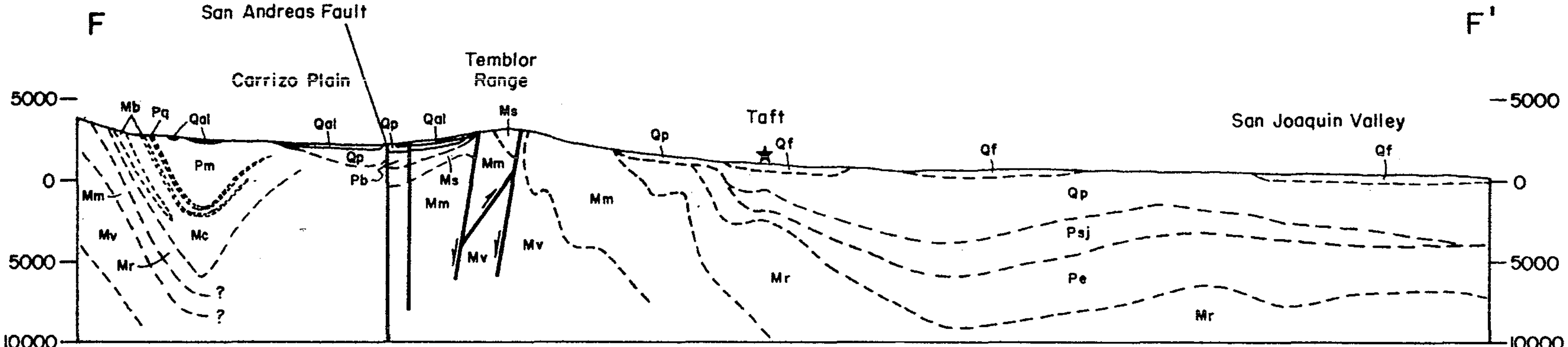
Ref: NUREG/0029, Vol. 2

GEOLOGIC MAP
LINCOLN SCHOOL
TAFT
PLATE C-2

GEOLOGIC CROSS-SECTION F-F'
LINCOLN SCHOOL
TAFT

Ref: NUREG/0029, Vol. 2

PLATE C-3



Modified after: 1) Dibblee (1962)
2) Hoots, Bear, & Kleinpell (1954)

Explanation

Qal	Alluvium, **Holocene in age**	Pe	Etchegoin Formation, middle and/or lower Pliocene in age
Qf	Alluvial fan deposits, **Holocene** in age	Mc	Caliente Formation, upper Miocene in age
Qp	Non-marine sedimentary deposits, Plio-Pleistocene in age	Mb	Basalt flows, upper Miocene in age
Pm	Morales Formation, Pliocene (Pleistocene ?) in age	Ms	Santa Margarita Formation, upper Miocene in age
Pq	Quatal Formation, Pliocene in age	Mr	Reef Ridge Formation, upper Miocene in age
Psj	San Joaquin Formation, upper Pliocene in age	Mm	Monterey Formation, upper and middle Miocene in age
Pb	Bitterwater Creek Formation, middle and/or lower Pliocene in age	Mv	Temblor and/or Vaqueros Formation, middle Miocene in age

Contact between geologic units

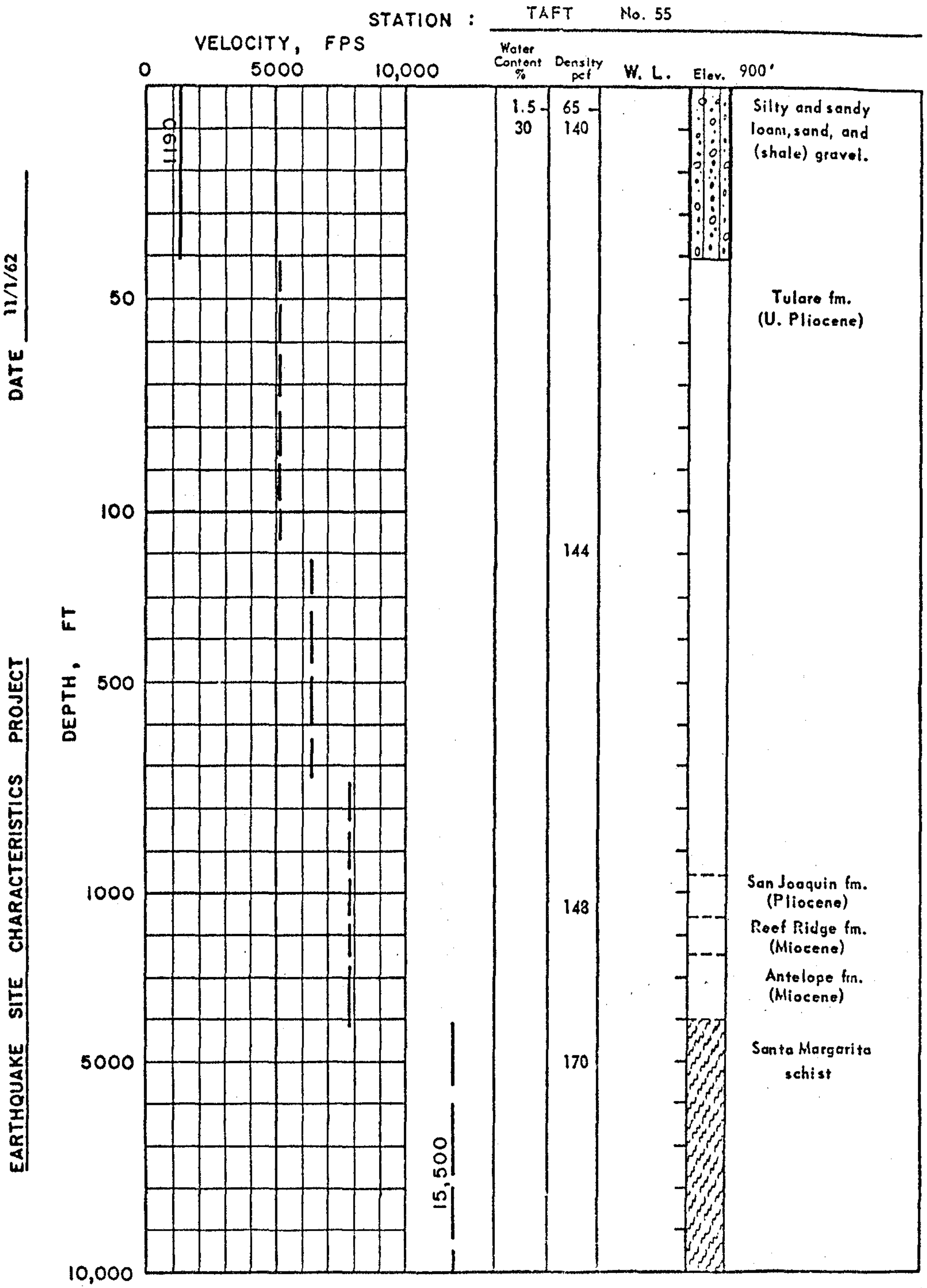
Fault

★ Accelerograph station, projected

0 5 10

Scale in miles

Note: See Fig. 6-4 for location of cross-section.



SITE CHARACTERISTICS, TAFT

Ref: Duke & Leeds, 1962

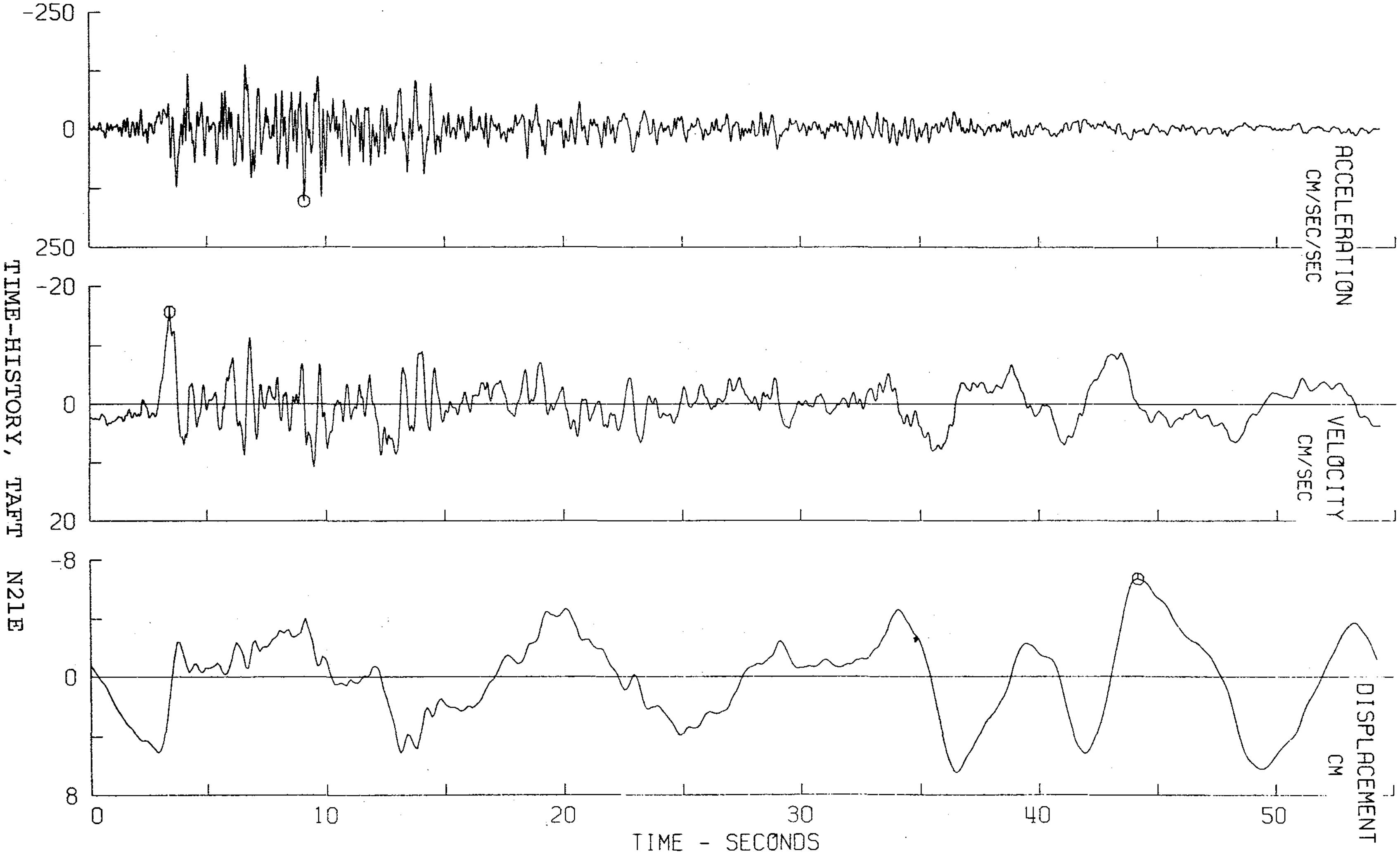
PLATE C-4

Ref: CIT/EERL 71-50

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP N21E

⊕ PEAK VALUES : ACCEL = 152.7 CM/SEC/SEC VELOCITY = -15.7 CM/SEC DISPL = -6.7 CM



TIME-HISTORY, TAFT N21E

PLATE C-5

Ref: CIT/EERL 71-50

TIME-HISTORY, TAFT S69E

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP S69E

⊙ PEAK VALUES : ACCEL = 175.9 CM/SEC/SEC VELOCITY = -17.7 CM/SEC DISPL = -9.2 CM

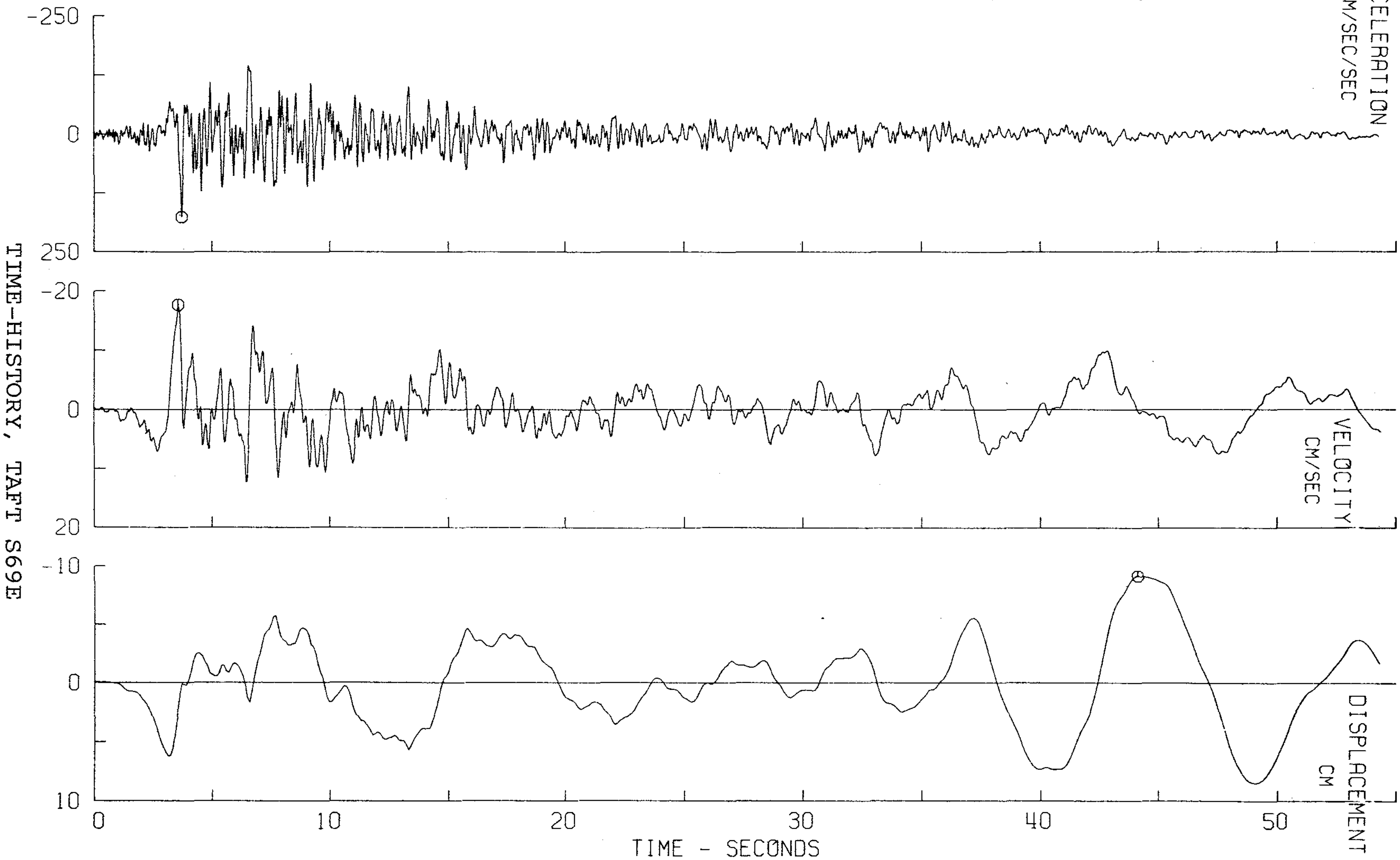
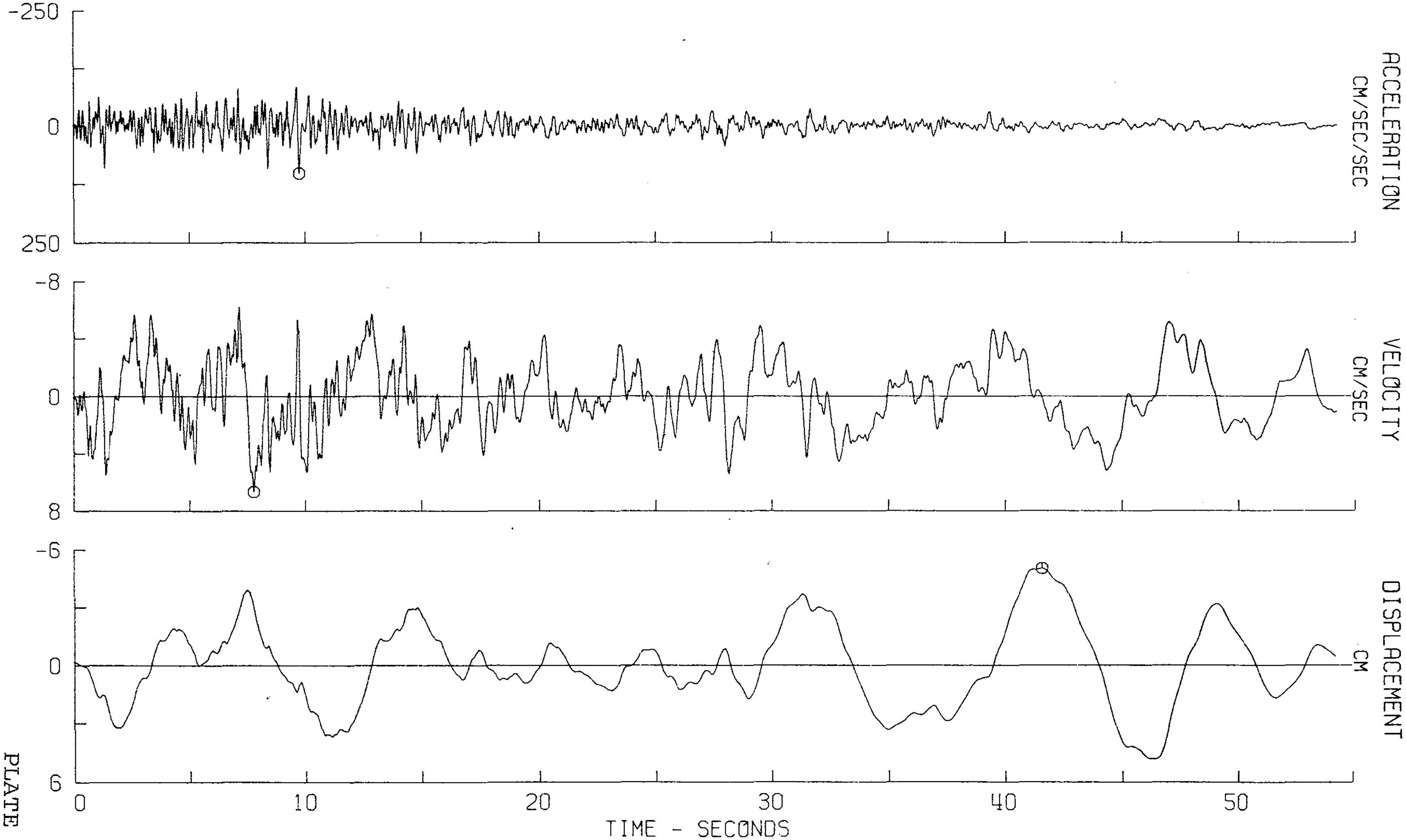


PLATE C-6

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP VERT

⦶ PEAK VALUES : ACCEL = 102.9 CM/SEC/SEC VELOCITY = 6.7 CM/SEC DISPL = -5.0 CM



Ref: CIT/EERL 71-50

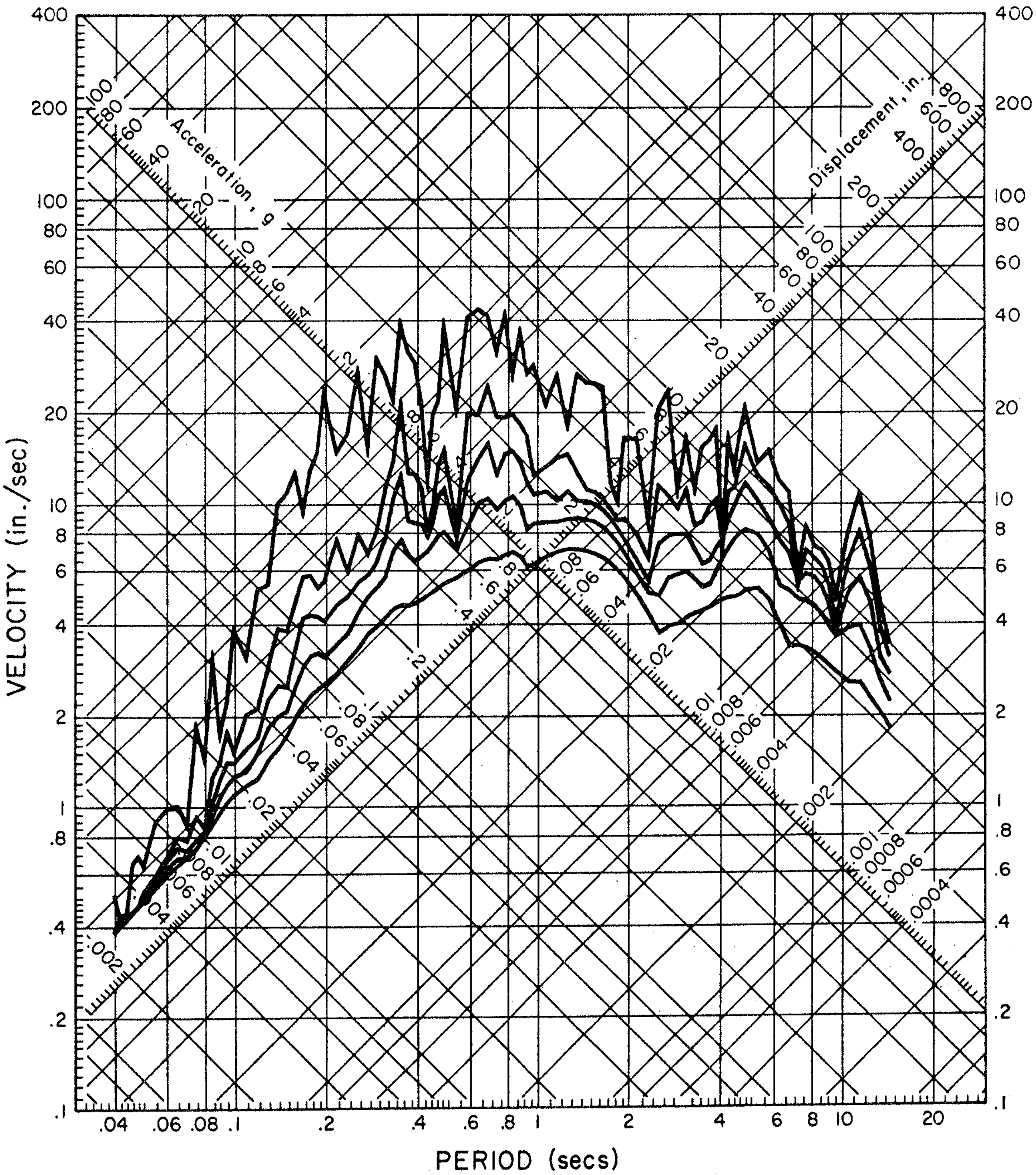
TIME-HISTORY, TAFT Vertical

PLATE C-7

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP N21E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, TAFT N21E

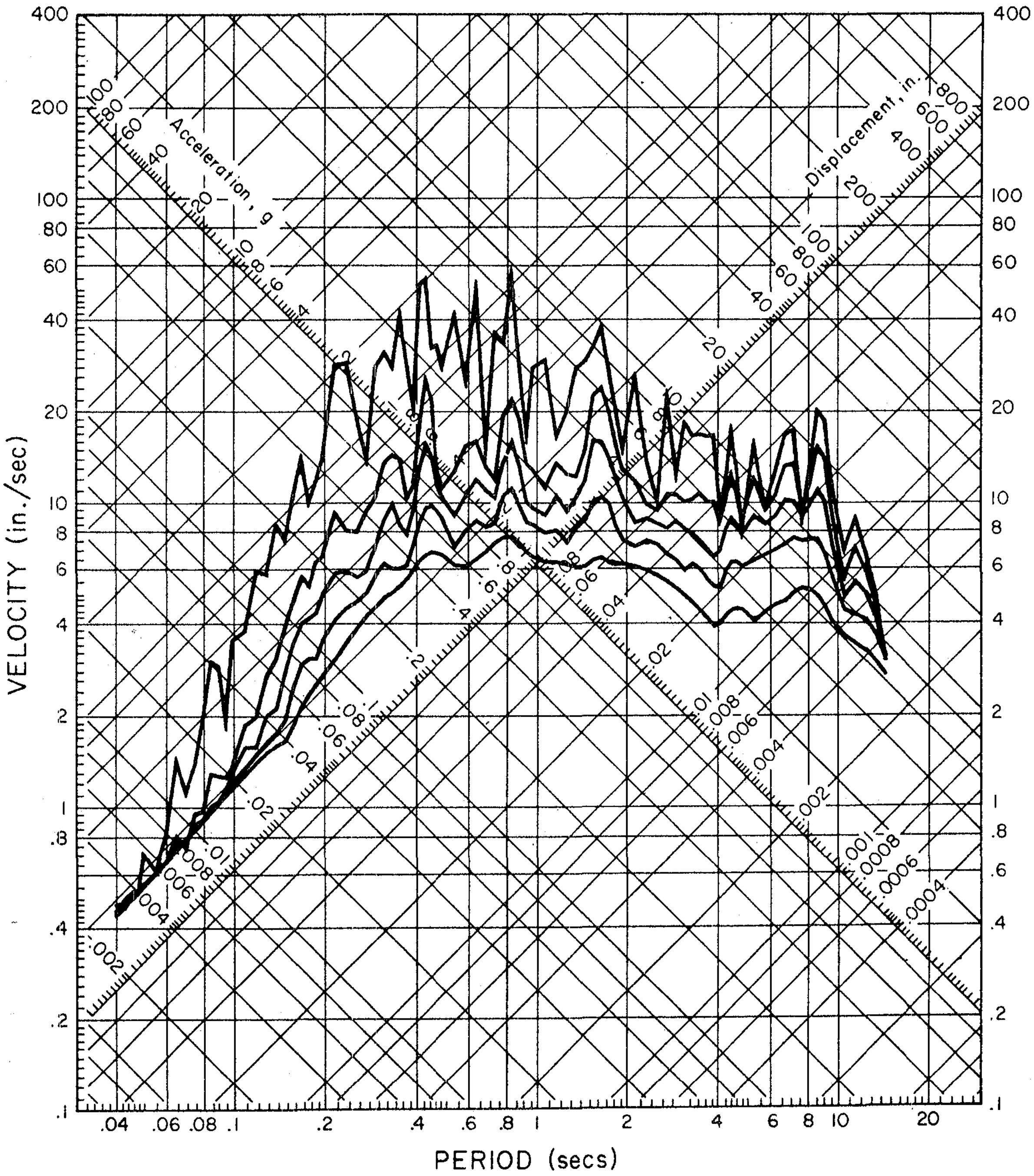
Ref: CIT/EERL 72-80

PLATE C-8

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP S69E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



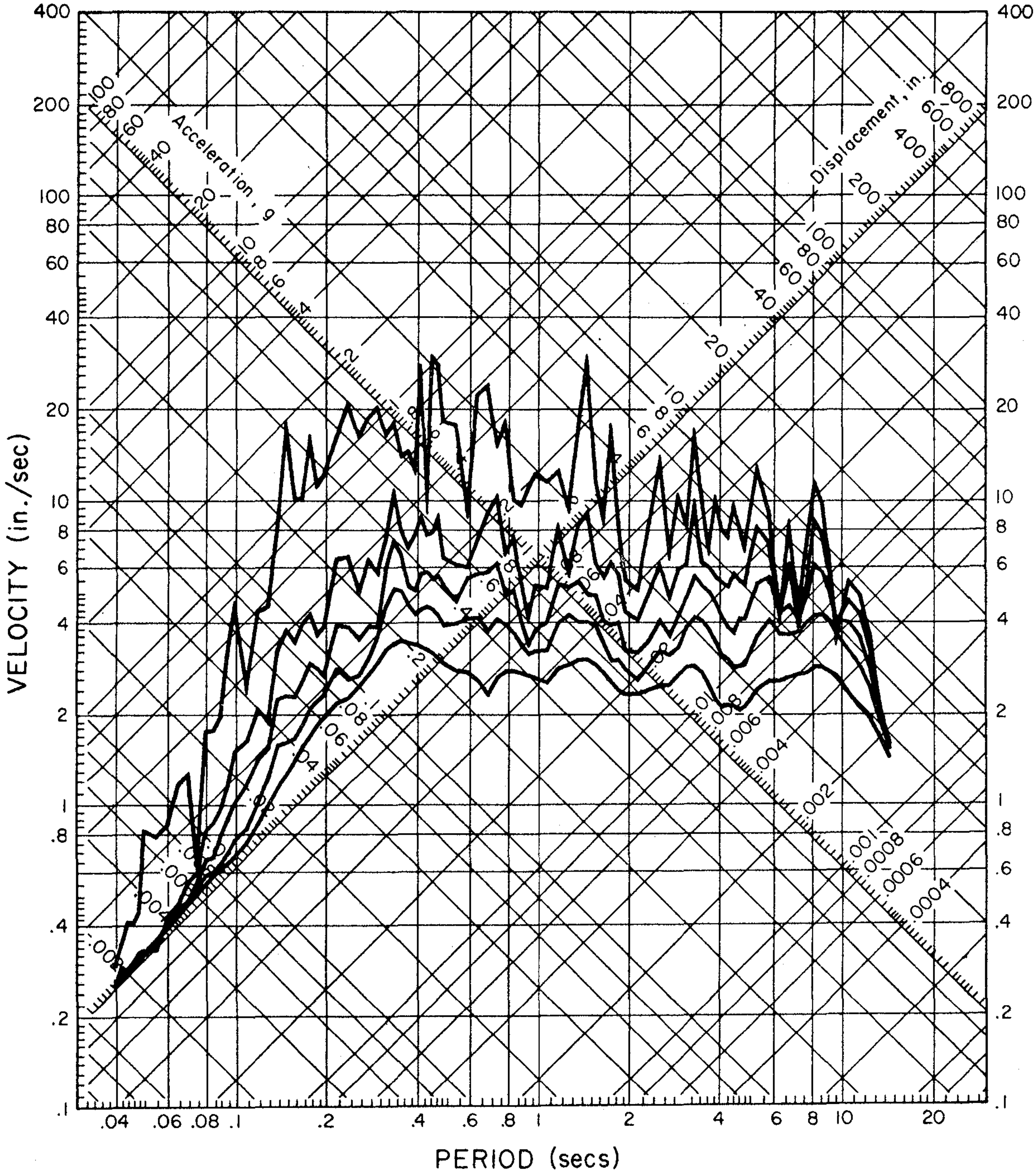
RESPONSE SPECTRUM, TAFT N69E

Ref: CIT/EERL 72-80 PLATE C-9

KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

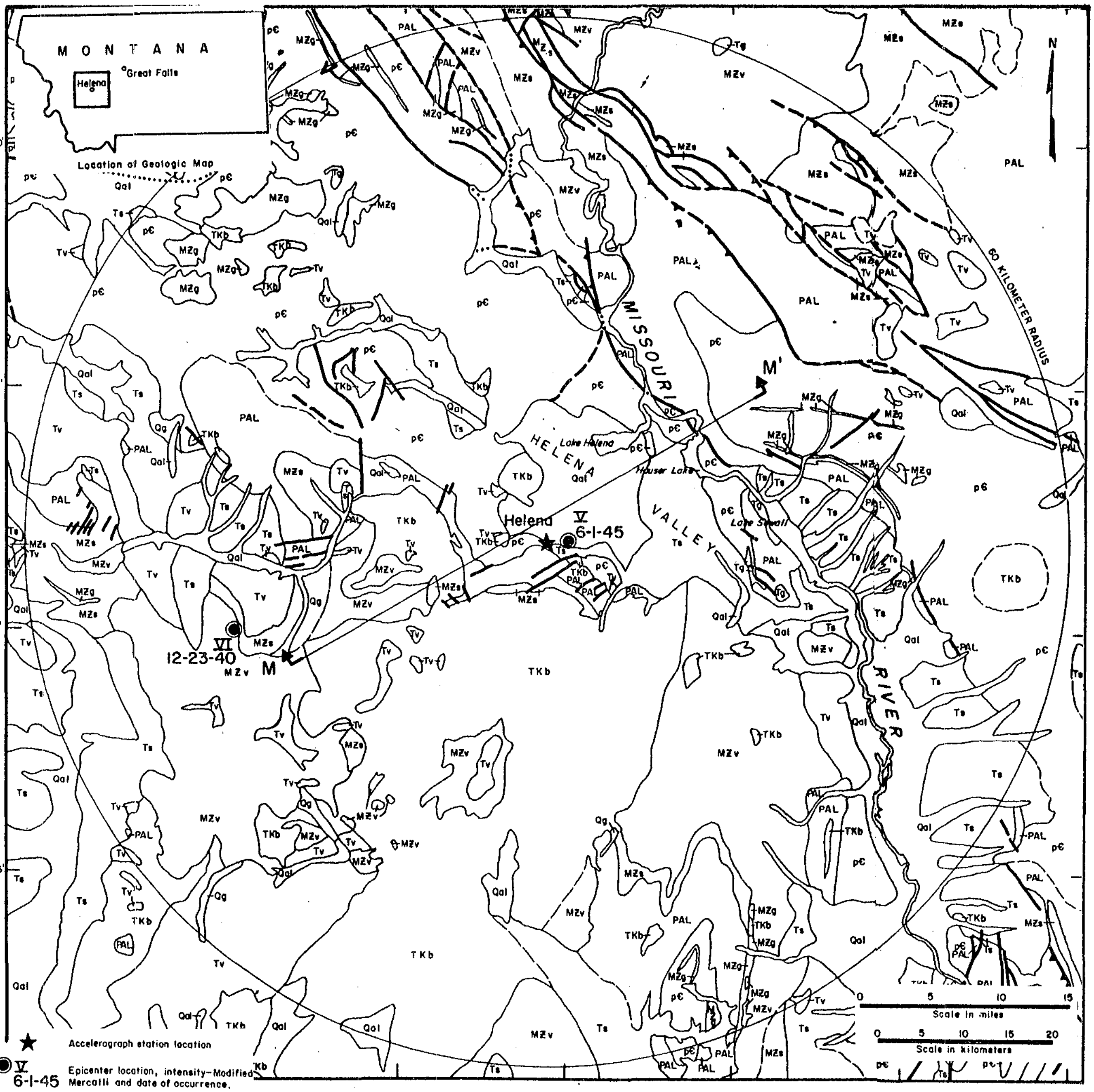
IIIA004 52.002.0 TAFT LINCOLN SCHOOL TUNNEL COMP VERT

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, TAFT Vertical

Ref: CIT/EERL 72-80 PLATE C-10



★ Accelerograph station location

◉ V 6-1-45 Epicenter location, intensity-Modified Mercalli and date of occurrence.

EXPLANATION

Contact — Dashed where approximately located

Fault — Dashed where approximately located, dotted where concealed

Thrust Fault — Barbs on upper plate, dashed where approximately located

Qal	Alluvium, Holocene in age; Includes some terrace deposits and glacial drift of Pleistocene age and some older alluvium of Pliocene age.	MZv	Mesozoic volcanic rocks; including some Tertiary volcanic rocks.
Qg	Glacial drift, Quaternary in age.	MZs	Mesozoic sedimentary rocks
Tv	Volcanic rocks, Tertiary in age.	MZg	Mesozoic intrusive rocks
Ts	Sedimentary rocks, Tertiary in age.	PAL	Paleozoic rocks, undifferentiated
Tg	Coarse grained intrusive rocks, Tertiary in age.	p€	Precambrian rocks, undifferentiated
TKb	Boulder batholith and broadly related stocks, Tertiary-Cretaceous in age.		

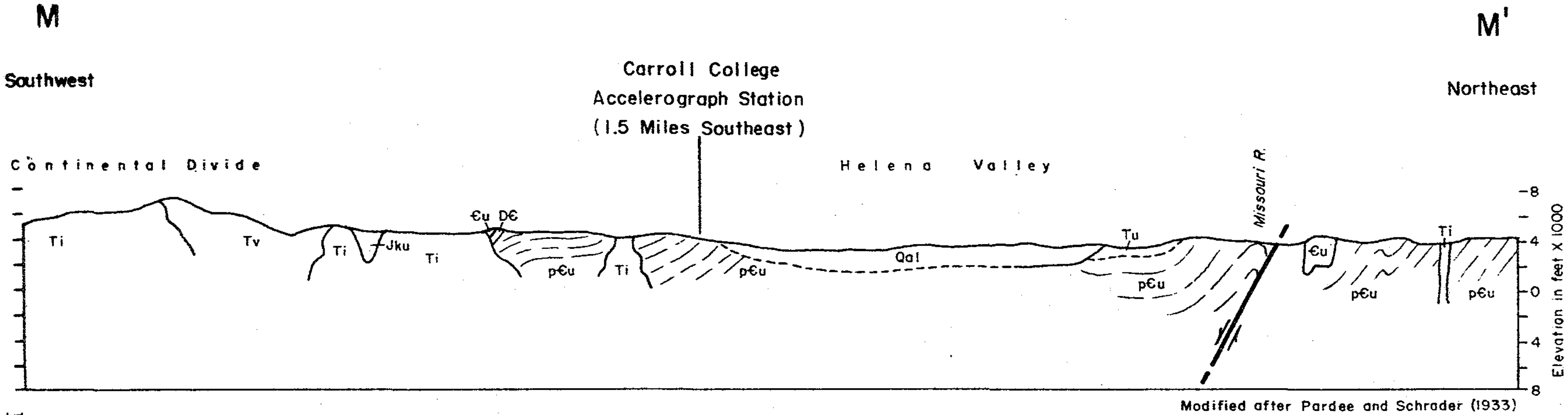
Notes:

1) Geology is simplified from Ross, et al (1955). To simplify, geologic map units on the above source map have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted.
2) Cross-section M-M' is shown on Fig. 13-5.
3) Earthquake magnitudes and epicentral locations are from U.S. Geological Survey files (unpublished).
4) Additional epicenters are listed in Table 13A-1 and appear on the Geologic Map for Montana State University, Bozeman, Montana, Fig. 10-4, (Section 10 of this Volume).

GEOLOGIC MAP
SCIENCE AND LIBRARY BUILDING
CARROLL COLLEGE
HELENA, MONTANA

Ref: NUREG/CR-0985, Vol. 3

PLATE C-11



EXPLANATION

Qal	Alluvium, Pleistocene and Recent in age (Qal)
Tu	Tertiary deposits, undifferentiated (Ts)
Ti	Intrusive rocks, Tertiary-Cretaceous in age (TKb)
Tv	Volcanic rocks, Tertiary-Cretaceous in age (Tv)
Jku	Sedimentary rocks, Jurassic-Cretaceous in age (PAL)
D€	Sedimentary rocks, Devonian-Cambrian in age (PAL)
€u	Sedimentary rocks, Cambrian in age (PAL)
p€u	Sedimentary rocks, Precambrian in age; Belt Series (p€)
———— - - -	Contact between geologic units, dashed where approximate or inferred
━━━━ ━ ━	Fault, dashed where approximate or inferred

0 2 4 6
Scale in miles

Notes: 1) For cross-section location see Fig. 13-4.
2) Abbreviations in parentheses refer to geologic symbols shown on Fig. 13-4.

GEOLOGIC CROSS-SECTION M-M'
SCIENCE AND LIBRARY BUILDING
CARROLL COLLEGE
HELENA, MONTANA

Ref: NUREG/CR-0985, Vol. 3

PLATE C-12

Ref: CIT/EERL 72-50

TIME-HISTORY, HELENA NOOE

HELENA, MONTANA EARTHQUAKE OCT 31, 1935 - 1138 MST

IIB025 35.001.0 HELENA, MONTANA CARROLL COLLEGE COMP N00E

⊙ PEAK VALUES : ACCEL = 143.5 CM/SEC/SEC VELOCITY = 7.3 CM/SEC DISPL = 1.4 CM

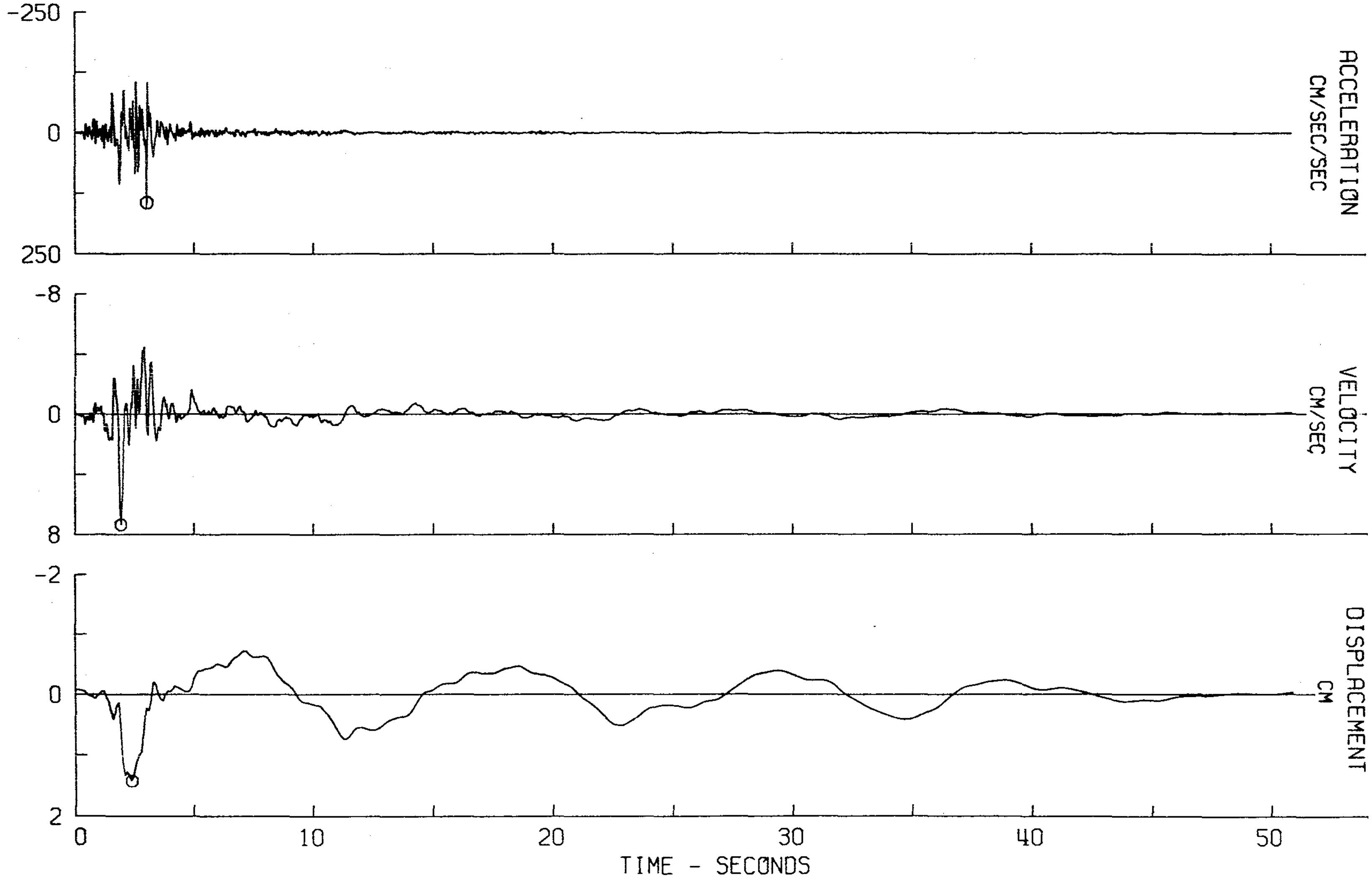


PLATE C-13

Ref: CIT/EERL 72-50

88

TIME-HISTORY, HELENA N90E

HELENA, MONTANA EARTHQUAKE   OCT 31, 1935 - 1138 MST

IIB025   35.001.0   HELENA, MONTANA CARROLL COLLEGE   COMP N90E

⊙ PEAK VALUES :   ACCEL = 142.5 CM/SEC/SEC   VELOCITY = -13.3 CM/SEC   DISPL = -3.7 CM

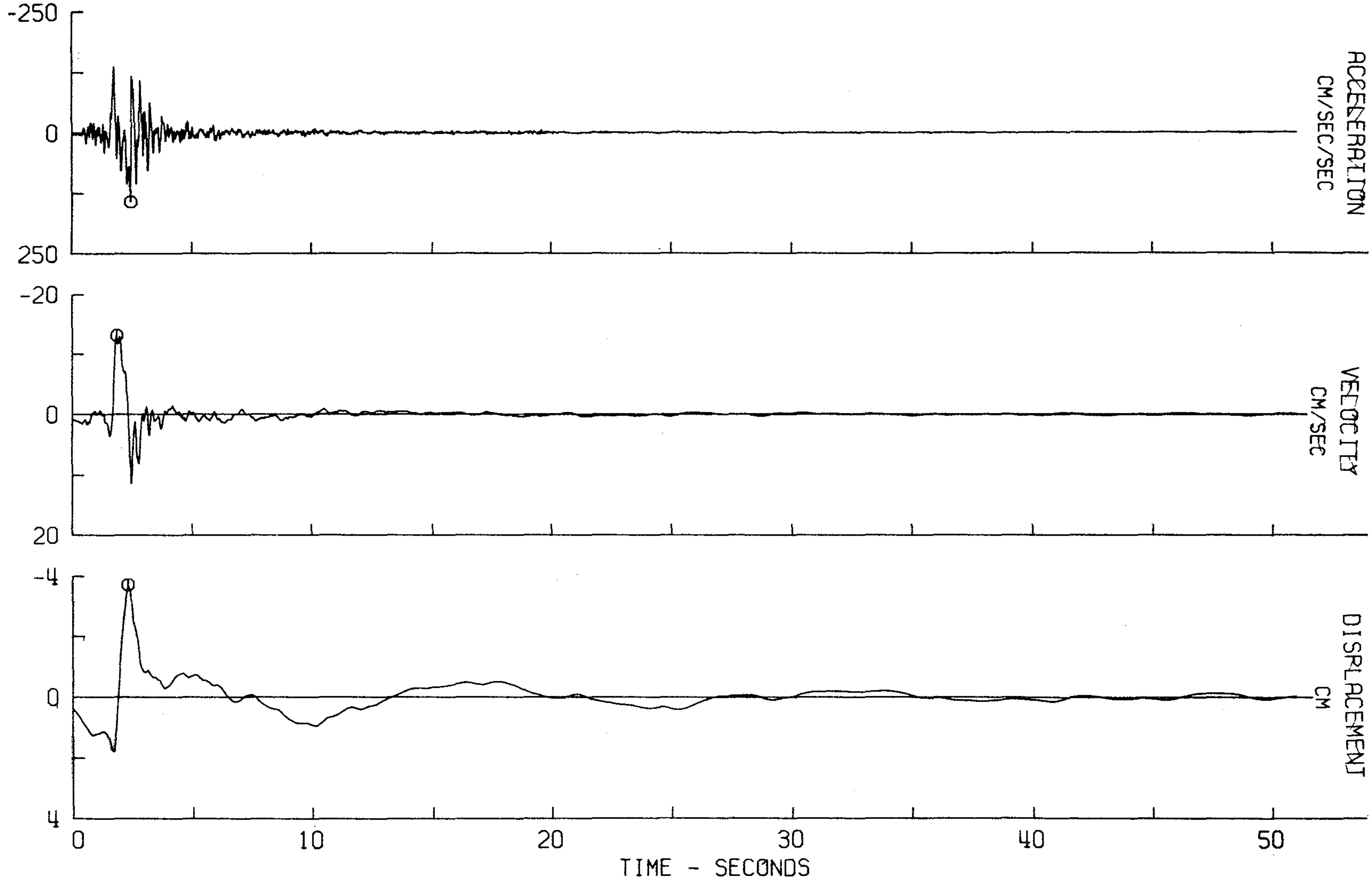


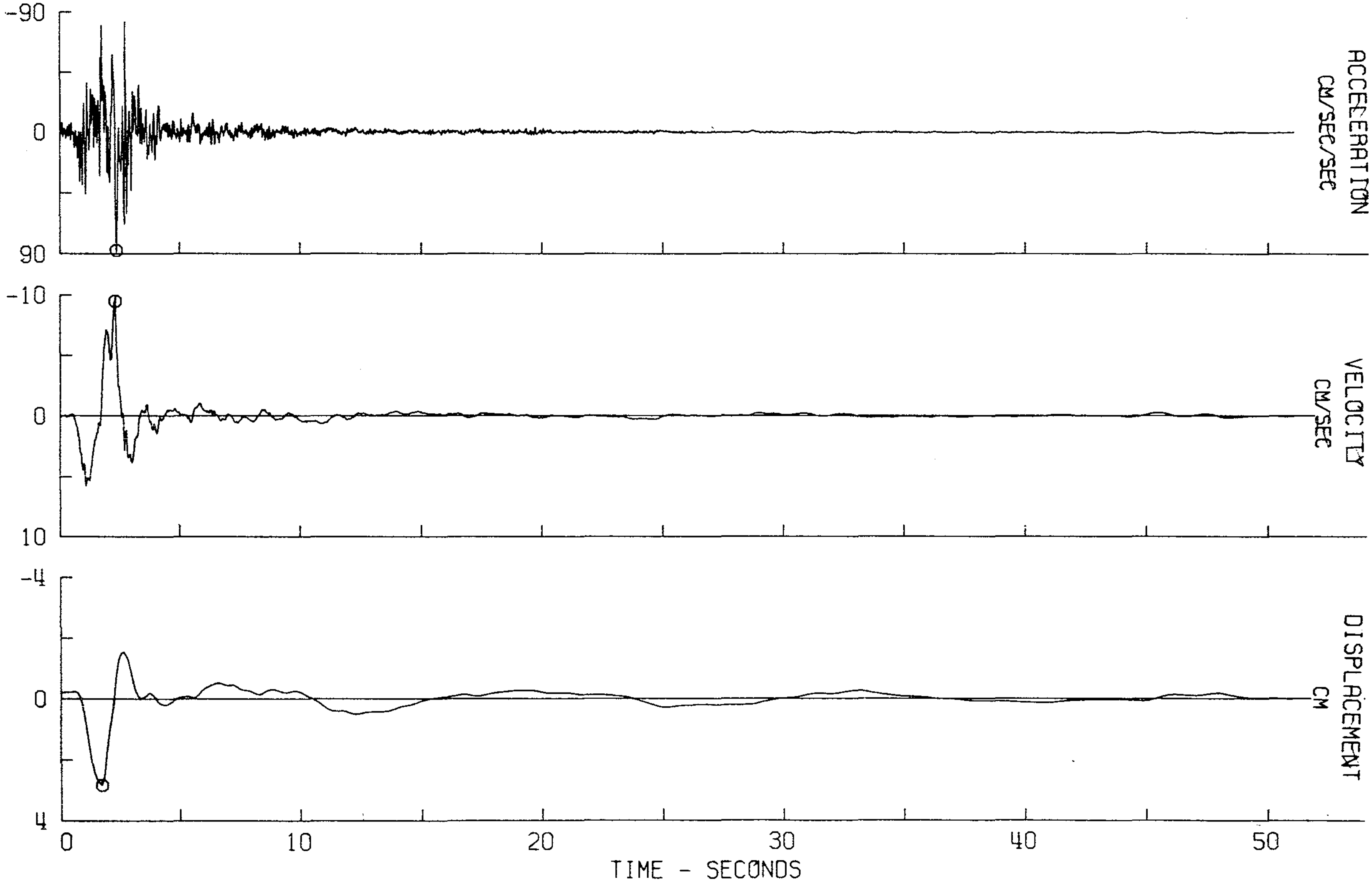
PLATE C-14

Ref: CIT/EERL 72-50

HELENA, MONTANA EARTHQUAKE OCT 31, 1935 - 1138 MST

IIB025 35.001.0 HELENA, MONTANA CARROLL COLLEGE COMP **Up**

⊙ PEAK VALUES : ACCEL = 87.5 CM/SEC/SEC VELOCITY = -9.5 CM/SEC DISPL = 2.8 CM



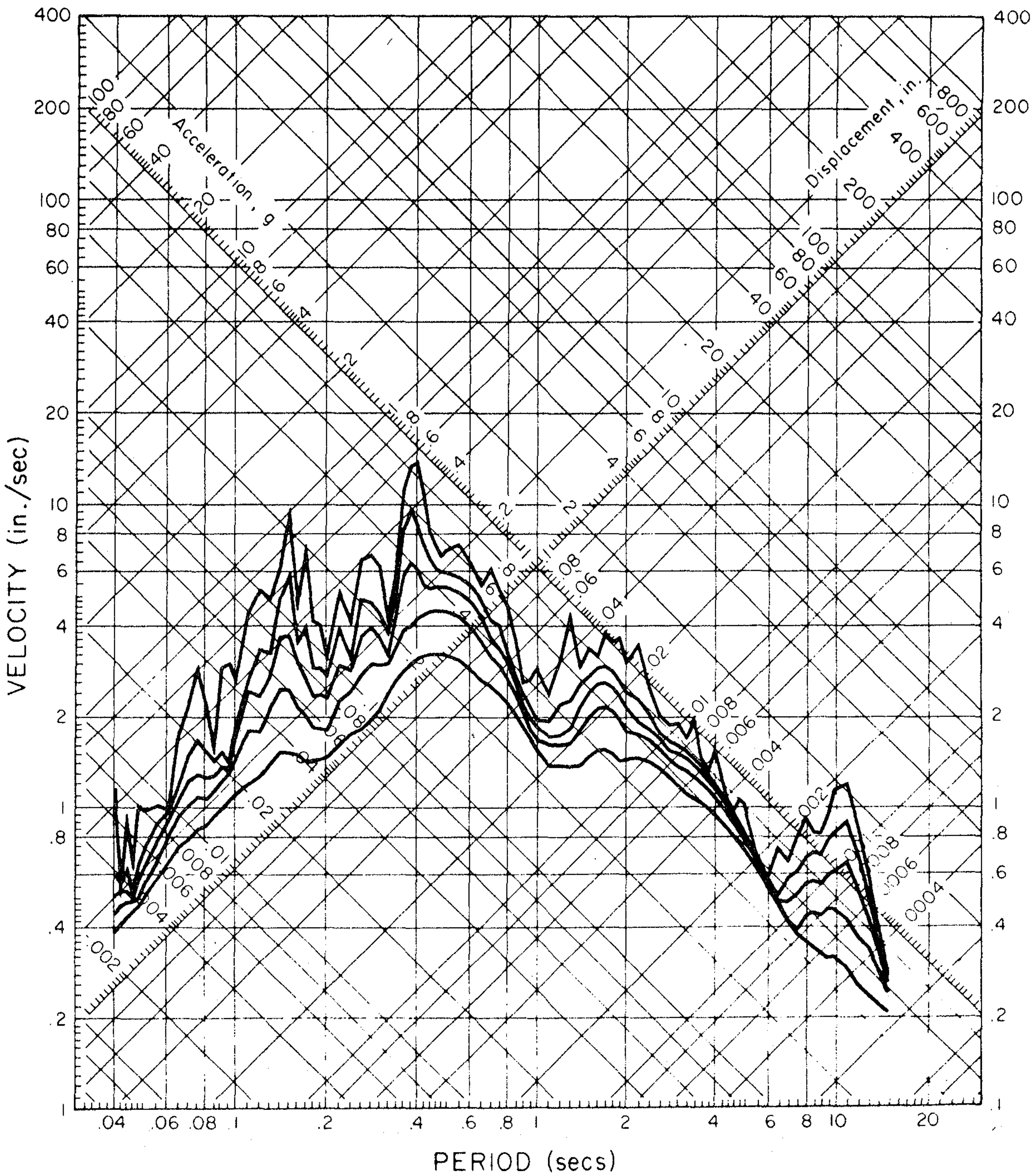
TIME-HISTORY, HELENA Vertical

PLATE C-15

HELENA, MONTANA EARTHQUAKE OCT 31, 1935 - 1138 MST

IIIB025 35.001.0 HELENA, MONTANA CARROLL COLLEGE COMP N00E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, HELENA N00E

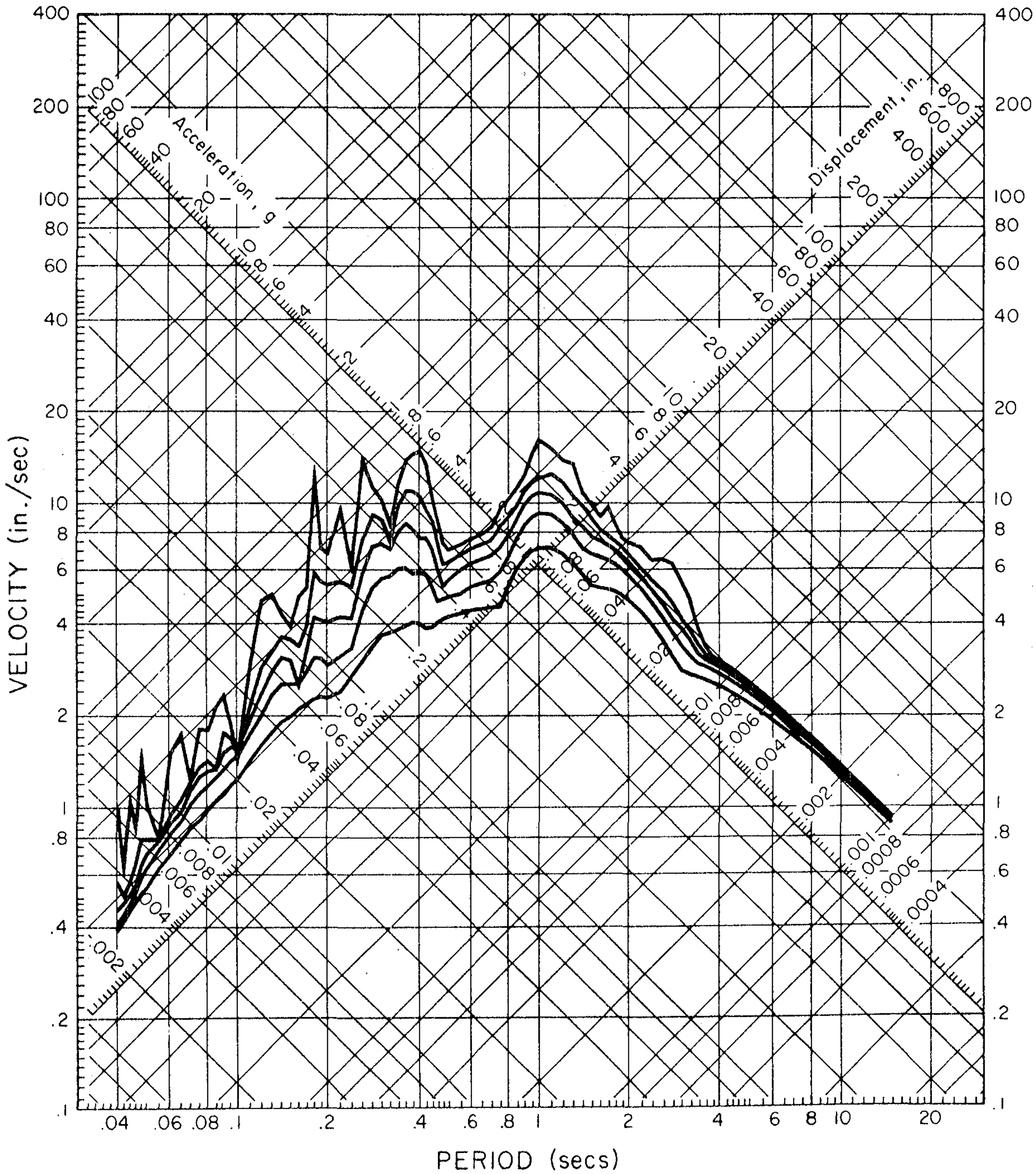
Ref: CIT/EERL 73-80

PLATE C-16

HELENA, MONTANA EARTHQUAKE   OCT 31, 1935 - 1138 MST

IIIB025 35.001.0   HELENA, MONTANA CARROLL COLLEGE   COMP N90E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, HELENA N90E

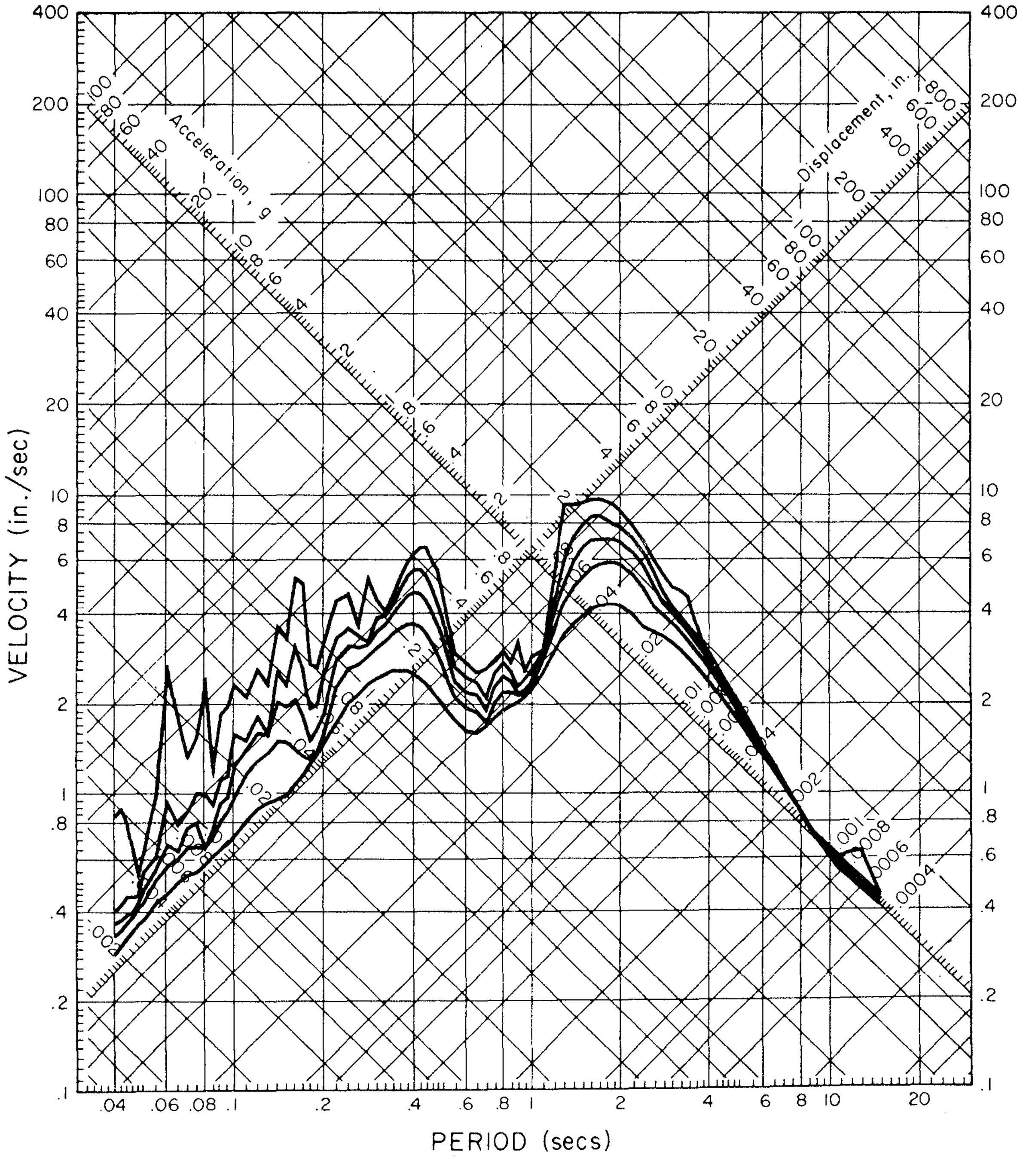
Ref: CIT/EERL 73-80

PLATE C-17

HELENA, MONTANA EARTHQUAKE OCT 31, 1935 - 1138 MST

IIIB025 35.001.0 HELENA, MONTANA CARROLL COLLEGE COMP Up

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

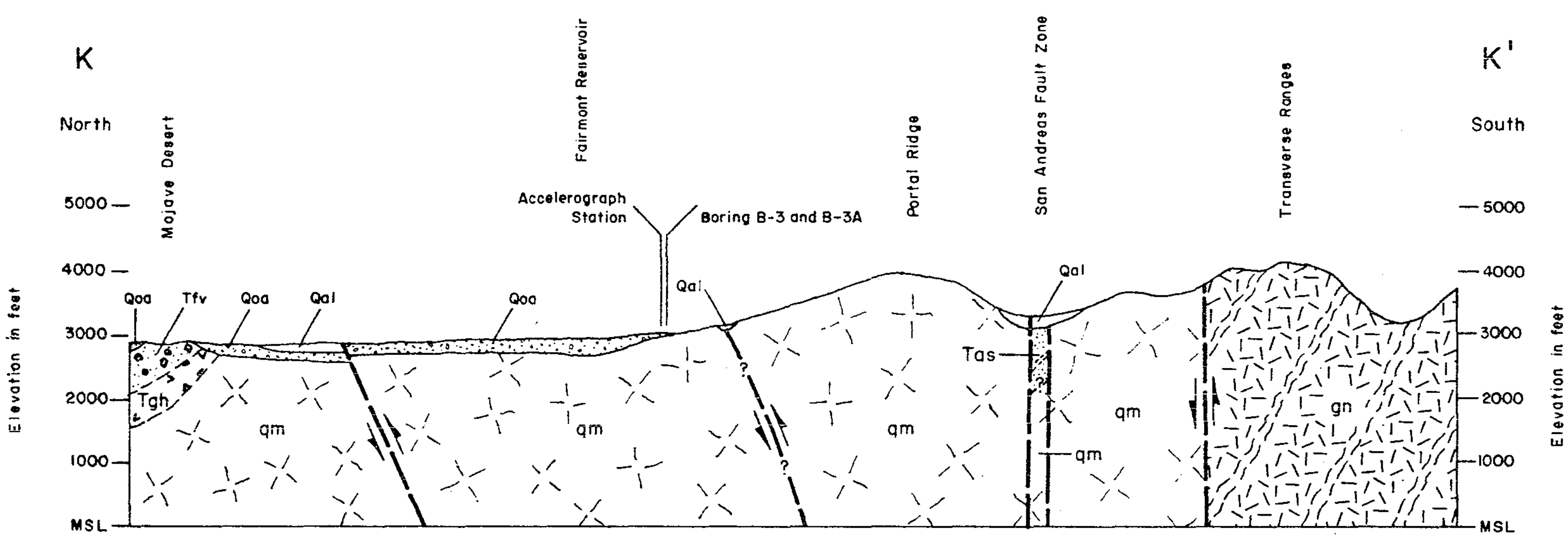


RESPONSE SPECTRUM, HELENA Vertical

Ref: CIT/EERL 73-80

PLATE C-18

Ref: NUREG/CR-0055, Vol. 1



Modified from Dibblee (1961)

EXPLANATION

Recent	Qal	Alluvial gravel, sand, and silt, includes some playa clay in the San Andreas fault zone (Qal)[2]
Pleistocene	Qoa	Older alluvial granitic sand and gravel (QP)
Pliocene	Tas	Anaverde Formation; arkosic sandstone with some shale and conglomerate. Occurs in San Andreas fault zone. (Ts)
Miocene (?)	Tfv	Fiss Fanglomerate; cobble–boulder fanglomerate (Ts)
	Tgh	Gem Hill Formation; pyroclastic rocks including lithic tuff and tuff breccia (Tv)
Mesozoic	qm	Dominantly quartz monzonite ranging in composition to granodiorite (gr)
Precambrian (?)	gn	Complex of gneiss and granitic rocks with average composition of granodiorite (p€g)

Notes:

1) See Fig. 2-19 for plan view of geologic cross-section K-K'
2) Abbreviations in parentheses refer to geologic symbols used on Fig 2-19
3) See Fig. 2-29 for log of boring B-3 and B-3A

0 1 2

Horizontal scale in miles

Vertical exaggeration 2X

For location of Cross-Section K-K'
see "Geologic Map, Lake Hughes No. 1".

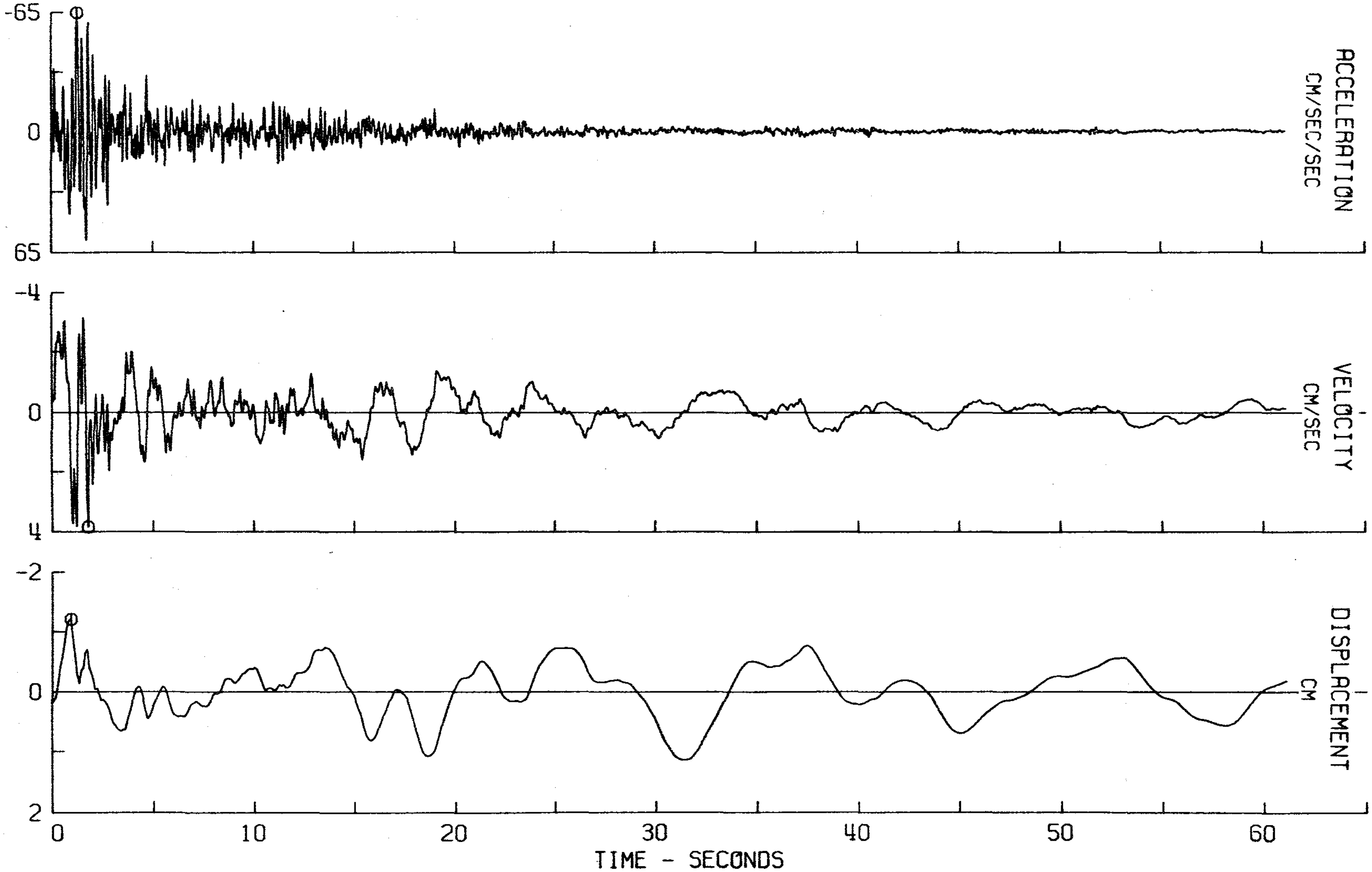
GEOLOGIC CROSS-SECTION K-K'
FAIRMONT RESERVOIR
FAIRMONT

PLATE C-19

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

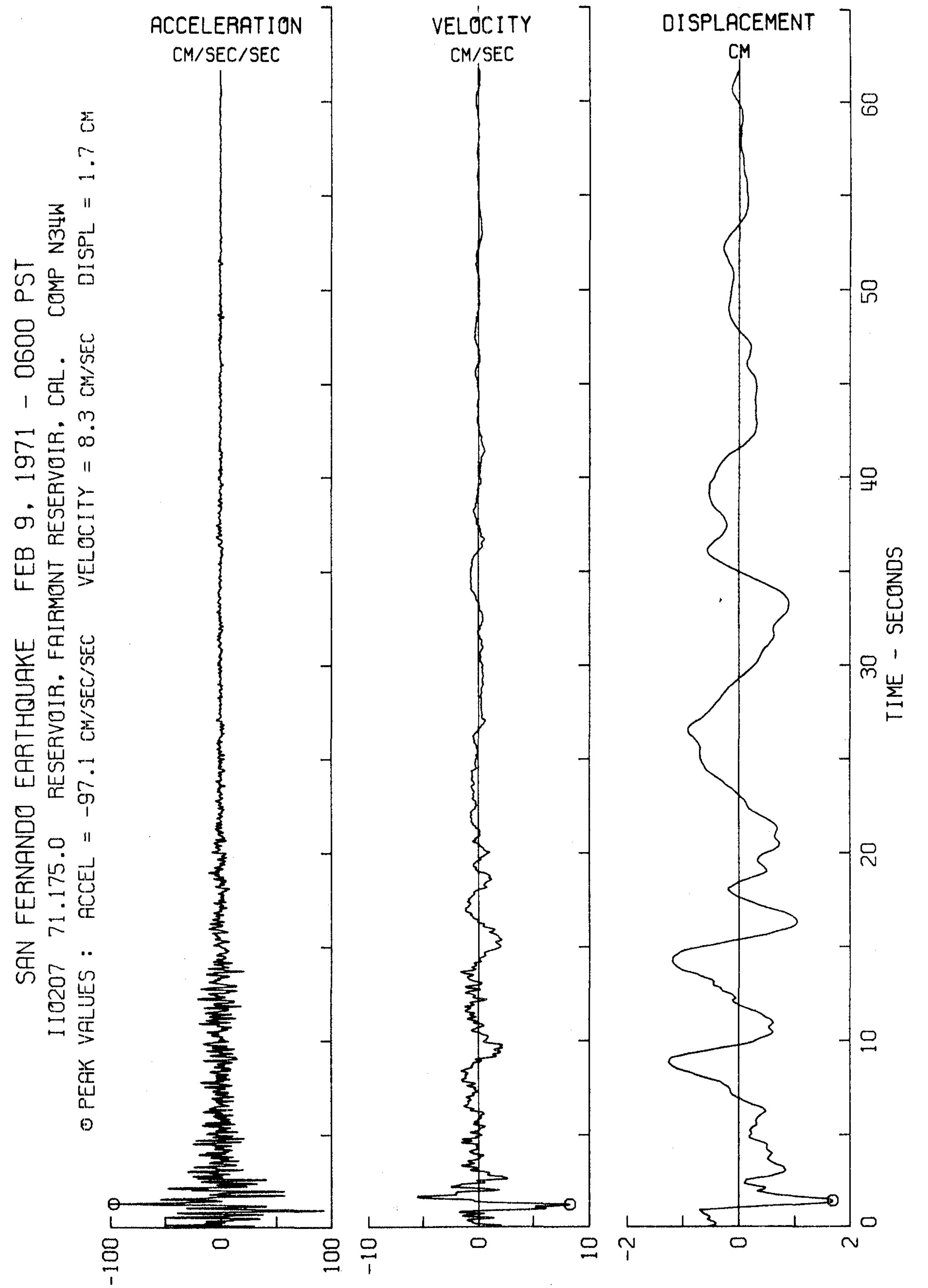
II0207 71.175.0 RESERVOIR, FAIRMONT RESERVOIR, CAL. COMP N56E

⦶ PEAK VALUES : ACCEL = -64.7 CM/SEC/SEC VELOCITY = 3.8 CM/SEC DISPL = -1.2 CM



TIME-HISTORY FAIRMONT RESERVOIR, N56E PLATE C-20

Ref: CIT/EERL 74-55



TIME-HISTORY, FAIRMONT RESERVOIR, N34 W PLATE C-21

Ref: CIT/EERL 74-55

Ref: CIT/EERL 74-55

TIME-HISTORY, FAIRMONT RESERVOIR, Vertical

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

II0207 71.175.0 RESERVOIR, FAIRMONT RESERVOIR, CAL. COMP UP

⊙ PEAK VALUES : ACCEL = -32.9 CM/SEC/SEC VELOCITY = 3.4 CM/SEC DISPL = -1.7 CM

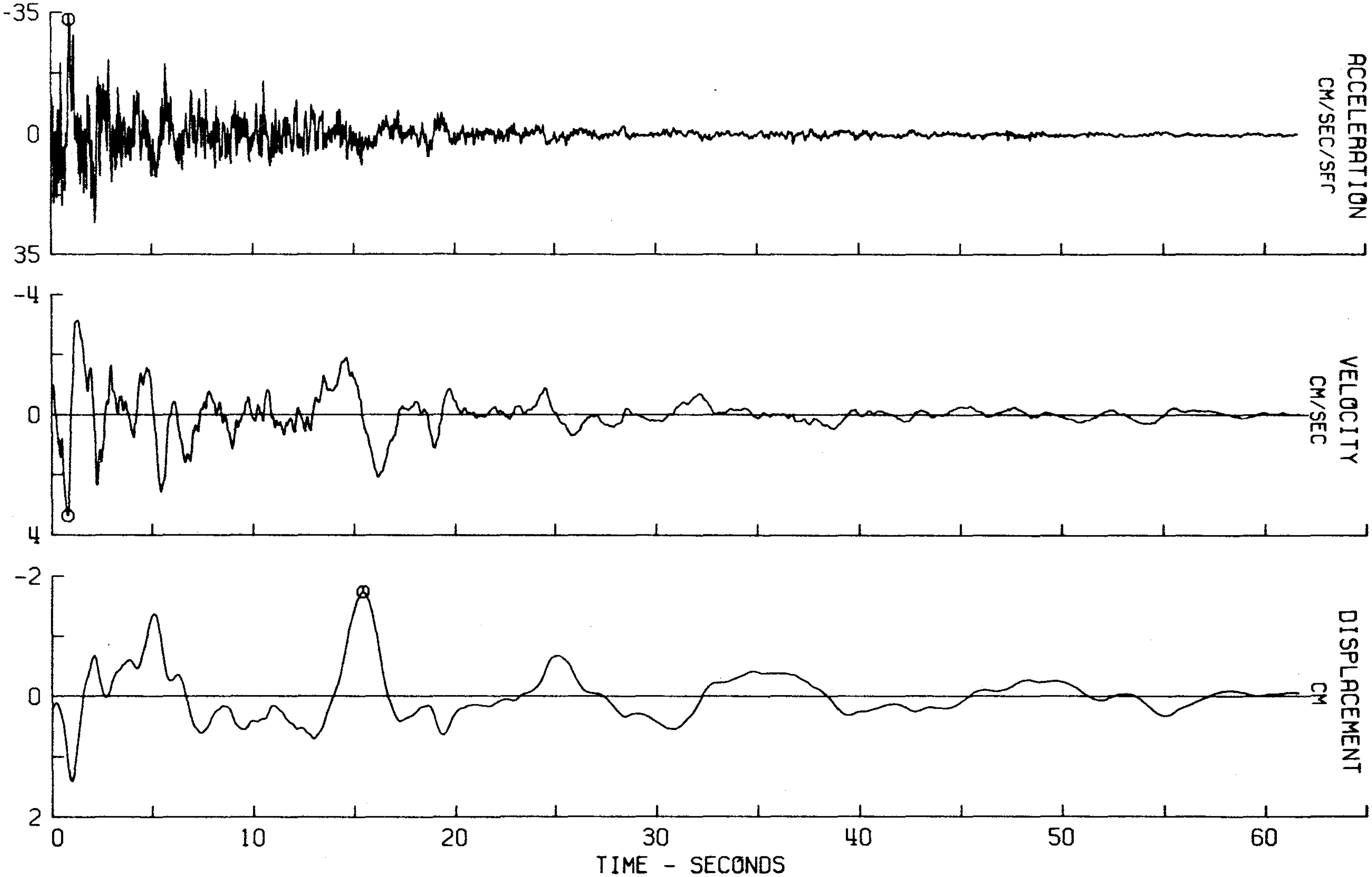
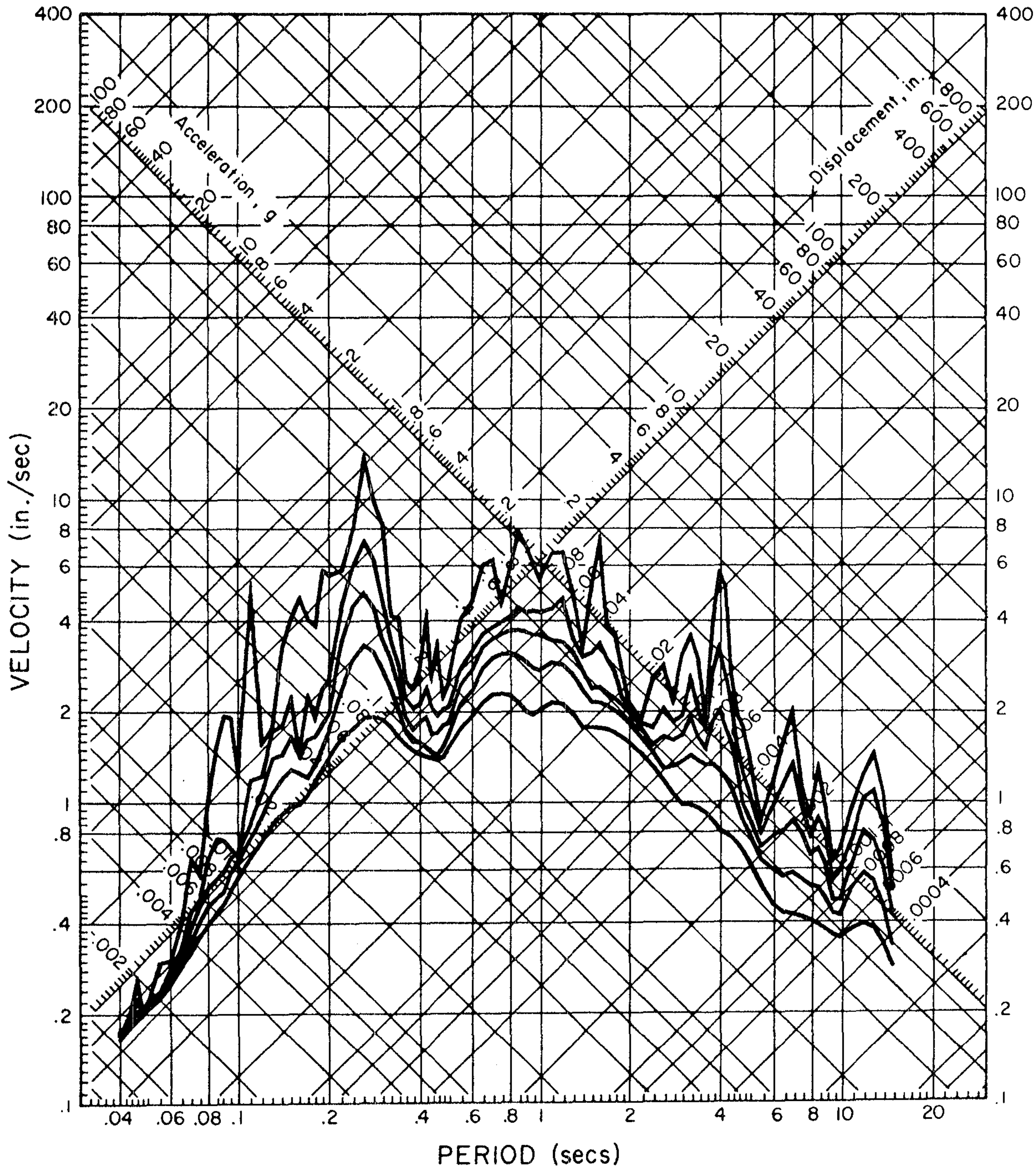


PLATE C-22

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

III0207 71.175.0 RESERVOIR, FAIRMONT RESERVOIR, CAL. COMP N56E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, FAIRMONT RESERVOIR, N56E

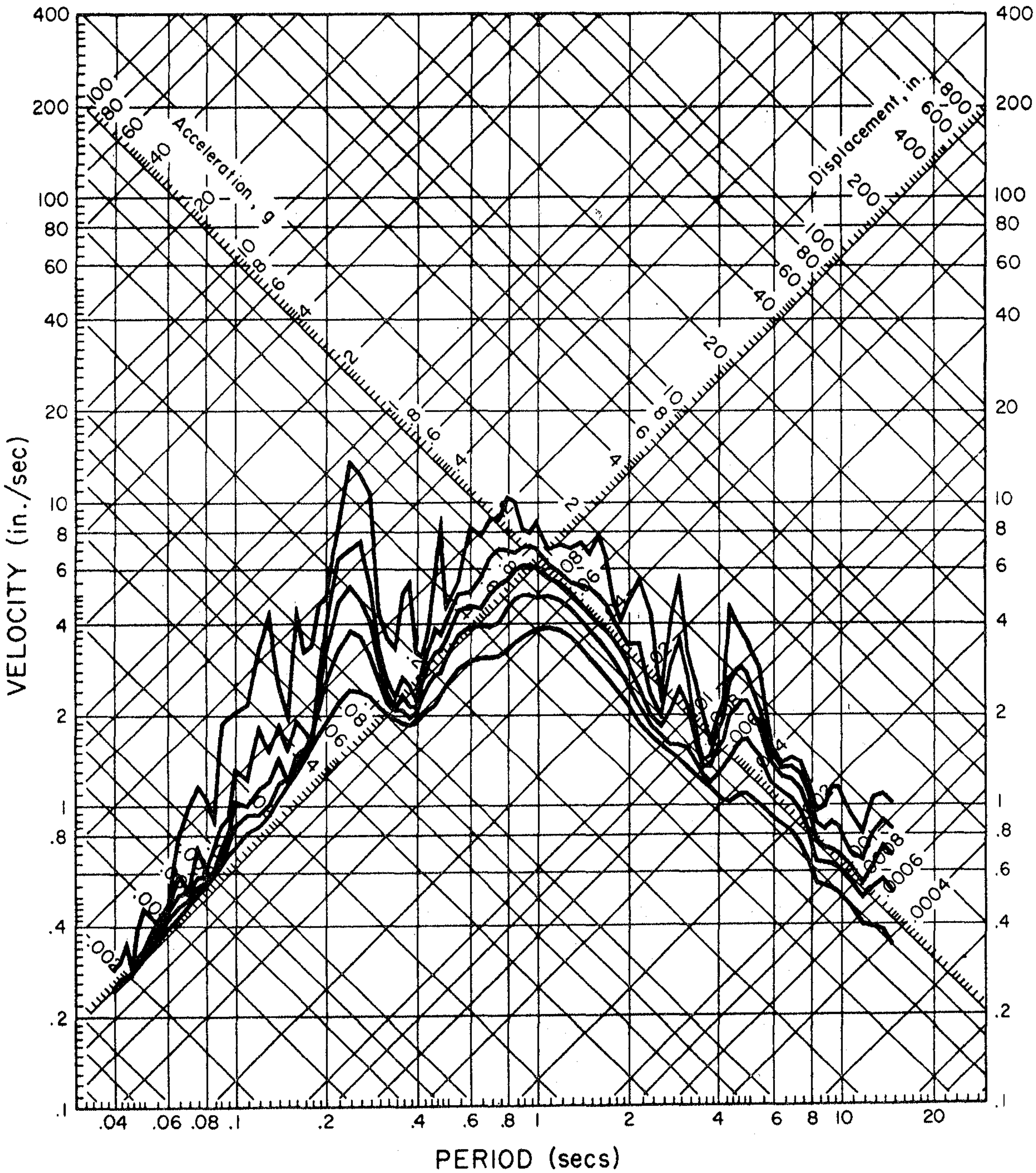
Ref: CIT/EERL 74-84

PLATE C-23

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

III0207 71.175.0 RESERVOIR, FAIRMONT RESERVOIR, CAL. COMP N34W

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



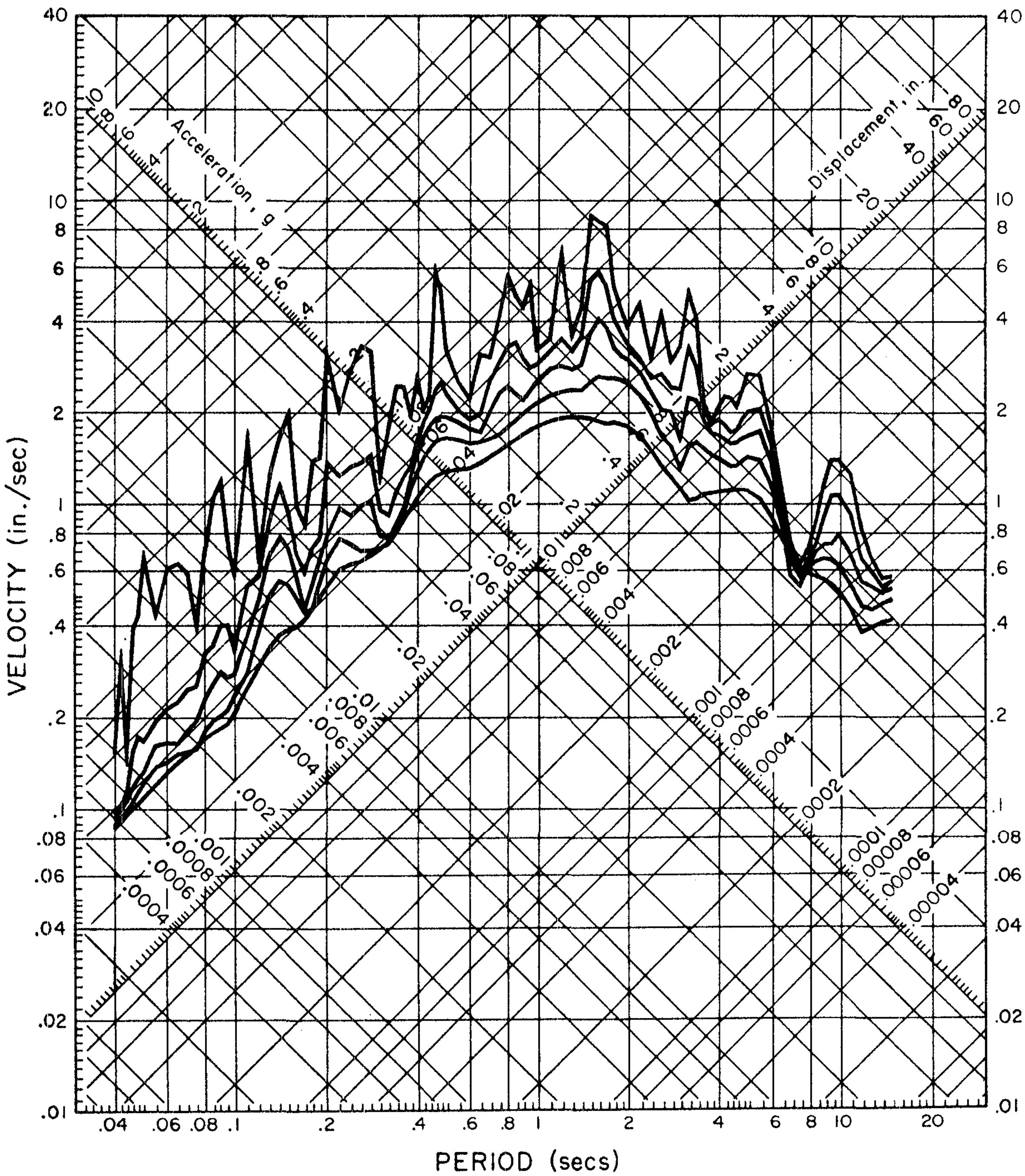
RESPONSE SPECTRUM, FAIRMONT RESERVOIR, N34W

Ref: CIT/EERL 74-84 PLATE C-24

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

III0207 71.175.0 RESERVOIR, FAIRMONT RESERVOIR, CAL. COMP UP

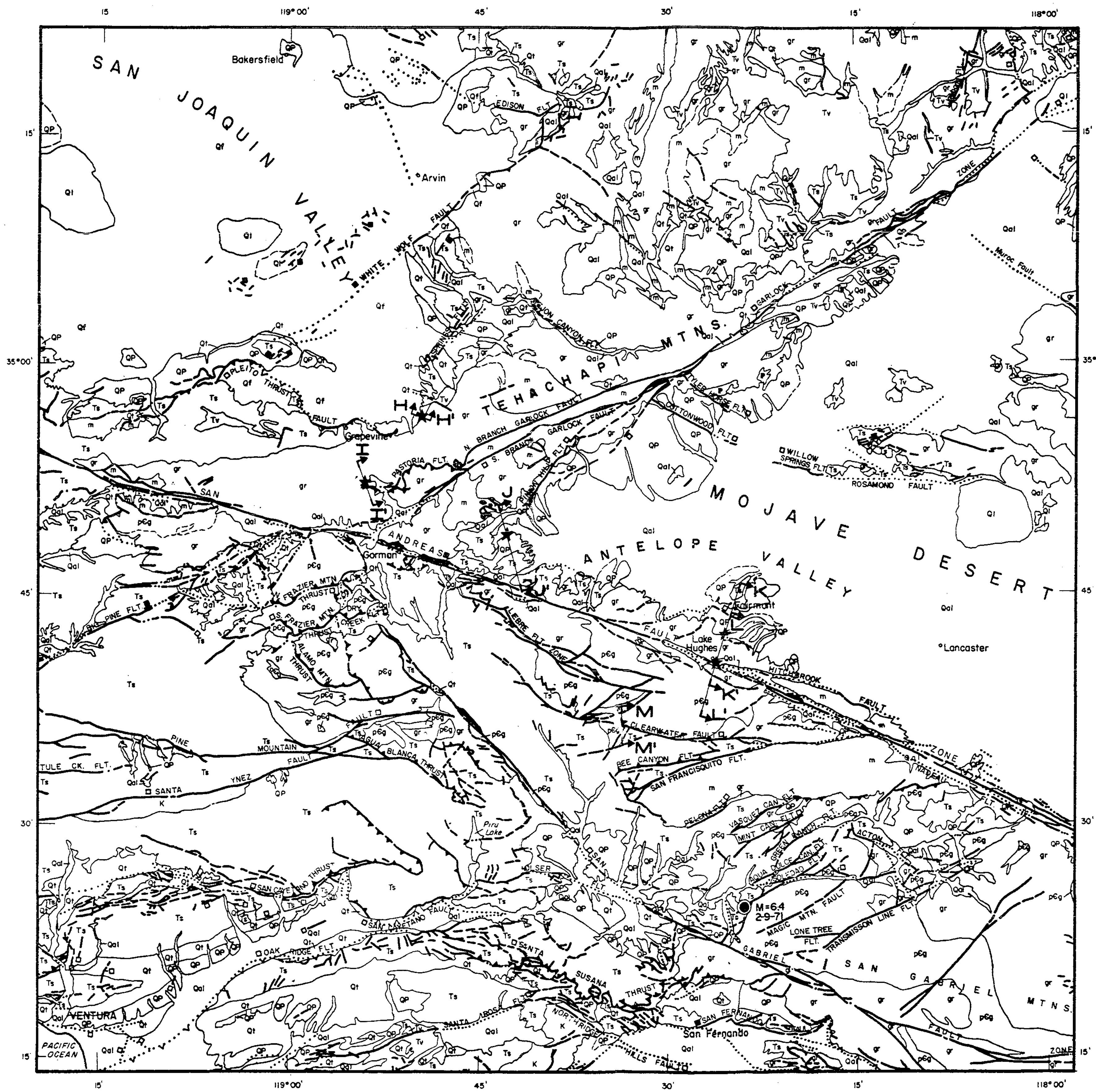
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, FAIRMONT RESERVOIR, Vertical

Ref: CIT/EERL 74-84

PLATE C-25



EXPLANATION

Qal	Alluvium, Recent in age; includes dune deposits.
Qf	Stream channel, fan, and basin deposits, Recent in age.
Ql	Lake deposits, Quaternary in age.
Qt	Marine deposits, marine and nonmarine terrace deposits, Quaternary in age; includes upper Pliocene marine deposits.
QP	Nonmarine sedimentary deposits, Plio-Pleistocene in age.
Tv	Volcanic rocks and igneous intrusive rocks, Tertiary in age.
Ts	Sedimentary rocks, Tertiary in age.
K	Sedimentary rocks, Cretaceous in age.
Mz	Mesozoic sedimentary rocks; also includes metamorphic rocks.
gr	Mesozoic granitic rocks; also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks.
m	Metamorphic and metasedimentary rocks, pre-Cretaceous in age.
P	Sedimentary and volcanic rocks, Paleozoic in age.
p€g	Precambrian igneous and metamorphic rocks; includes crystalline rocks which may be as young as Mesozoic.

★	Seismograph Station location.
M=5.7 6-5-60	Epicenter location, Richter magnitude, and date of occurrence.
□	Faults that have moved during Quaternary time without historic record (approx. past 2 million years)
■	Faults that have moved during historic time (approx. 200 years).
Contact	Dashed where approximately located.
Fault	Dashed where approximately located, dotted where concealed, queried where existence is uncertain.
Thrust Fault	Barbs on upper plate, dashed where approximately located, dotted where concealed.
	Cross-section location. Sections H-H', I-I', J-J', K-K', L-L', and M-M' are shown respectively on Fig. 2-20 through Fig. 2-25.

NOTES:

1) Geology is simplified from Jennings and Strand (1969), Smith (1964), Rogers (1967), and Jennings, Burnett and Troxel (1962). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1973).

2) Information on fault activity (Quaternary activity, Historic activity) is from Jennings (1973). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1973, for details).

3) Individual faults within the San Andreas fault zone show evidence of Quaternary and Historic activity (See Jennings, 1973, for details).

4) Heavy border on boxes indicates units that appear on this figure.

5) Plan view of cross-section H-H' is also shown on Fig. 2-1.

6) Earthquake magnitude and epicentral location are from Hudson et al (1974a).

Location of Geologic Map

0 5 10 15
Scale in miles

0 5 10 15 20
Scale in kilometers

N

GEOLOGIC MAP
NORTHERN MOUNTAINS DISTRICT
SOUTHERN CALIFORNIA

LAKE HUGHES NO. 1
PLATE C-26

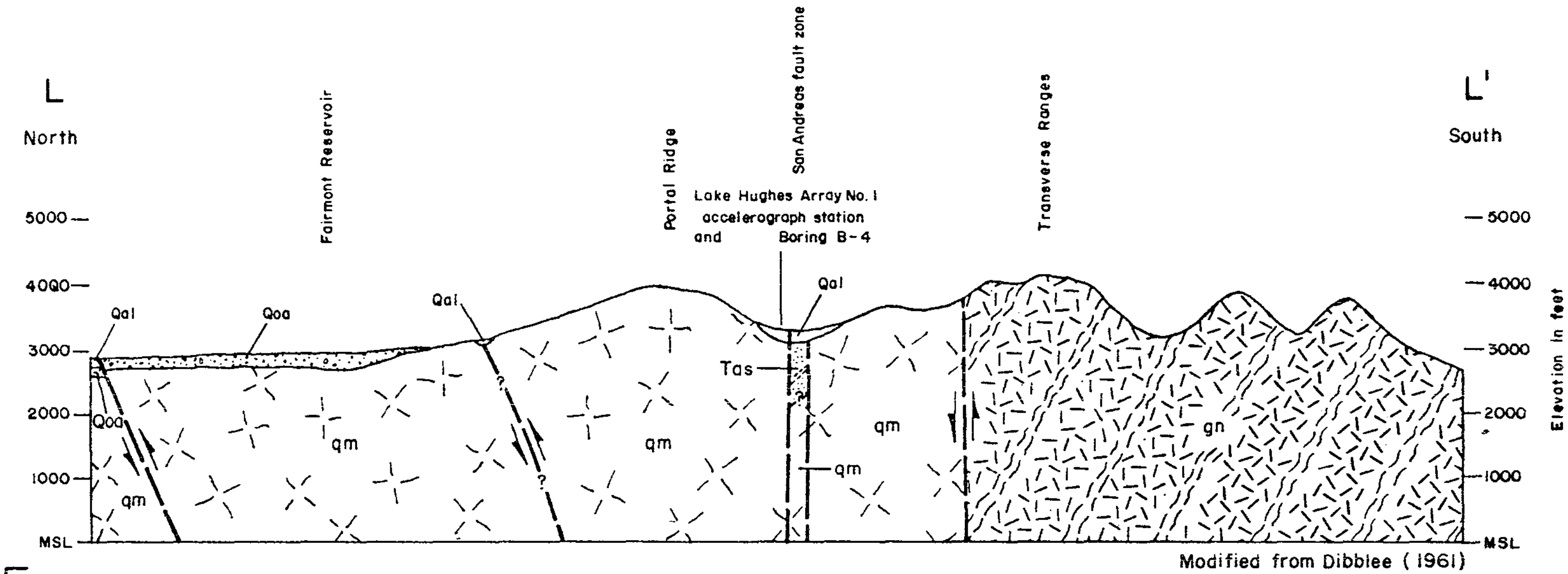
FIG. 2-19

Ref: NUREG/CR-0055, Vol. 1

Ref: NUREG/CR-0055, Vol. 1

GEOLOGIC SECTION, LAKE HUGHES NO. 1

GEOLOGIC CROSS-SECTION L-L'
LAKE HUGHES ARRAY NO. I
LOS ANGELES CO. FIRE STATION NO. 78
LAKE HUGHES



Modified from Dibblee (1961)

EXPLANATION

Recent	Qal	Alluvial gravel, sand, and silt, includes some playa clay in the San Andreas fault zone (Qal)[2]
Pleistocene	Qoa	Older alluvial granitic sand and gravel (QP)
Pliocene	Tas	Anaverde Formation; arkosic sandstone with some shale and conglomerate. Occurs in San Andreas fault zone.(Ts)
Mesozoic	qm	Dominantly quartz monzonite ranging in composition to granodiorite (gr)
Precambrian (?)	gn	Complex of gneiss and granitic rocks with average composition of granodiorite (p€g)

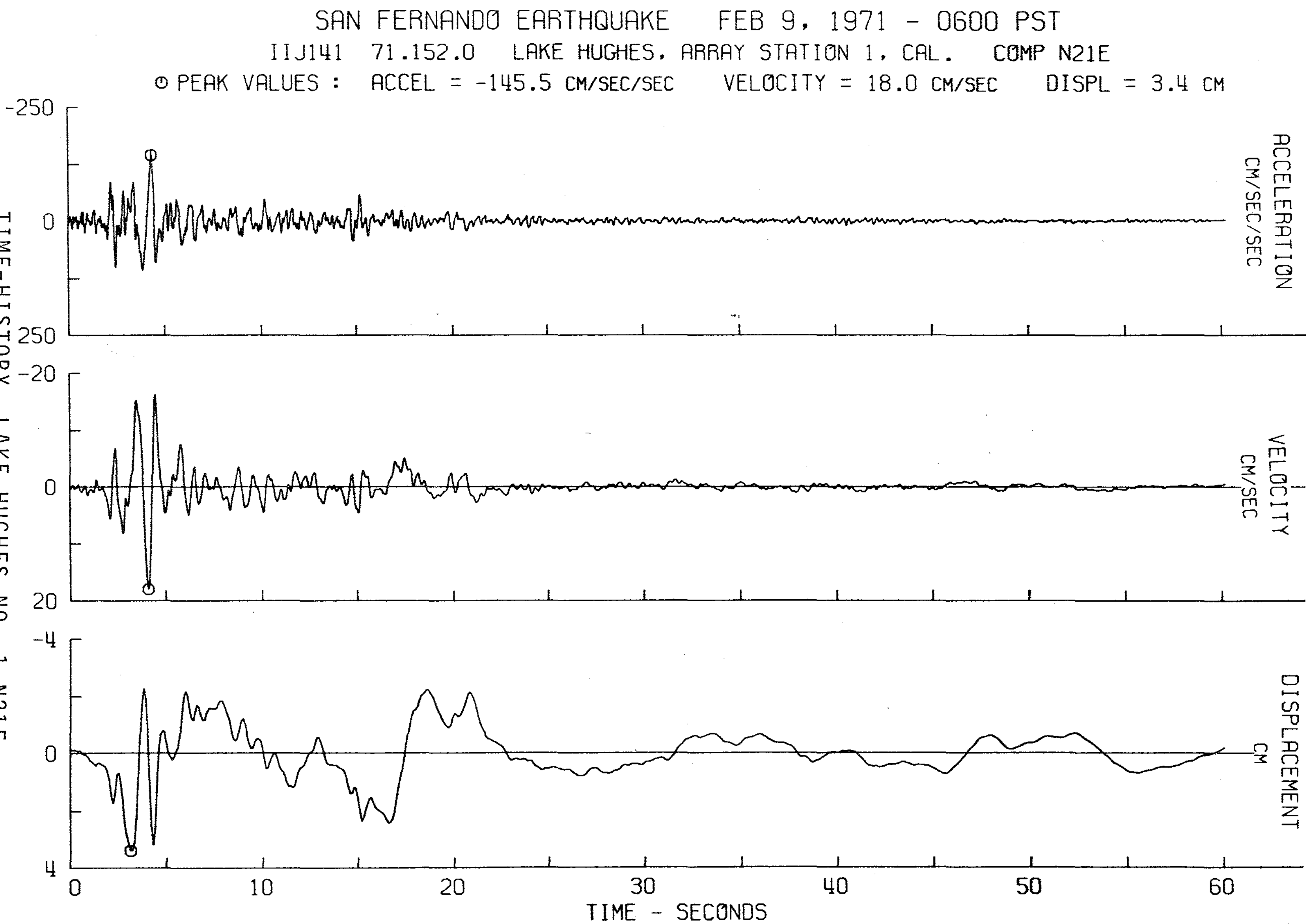
Notes:

1) See Fig. 2-19 for plan view of geologic cross-section L-L'.
2) Abbreviations in parentheses refer to geologic symbols used on Fig. 2-19.
3) See Fig. 2-30 for log of boring B-4.

0 1 2
Horizontal scale in miles
Vertical exaggeration 2X

PLATE C-27

Ref: CIT/EERL 74-52



TIME-HISTORY, LAKE HUGHES NO. 1, N21E

PLATE C-28

Ref: CIT/EETL 74-52

TIME-HISTORY, LAKE HUGHES NO. 1, S69E

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIJ141 71.152.0 LAKE HUGHES, ARRAY STATION 1, CAL. COMP S69E

⊙ PEAK VALUES : ACCEL = 108.9 CM/SEC/SEC VELOCITY = -14.4 CM/SEC DISPL = -2.9 CM

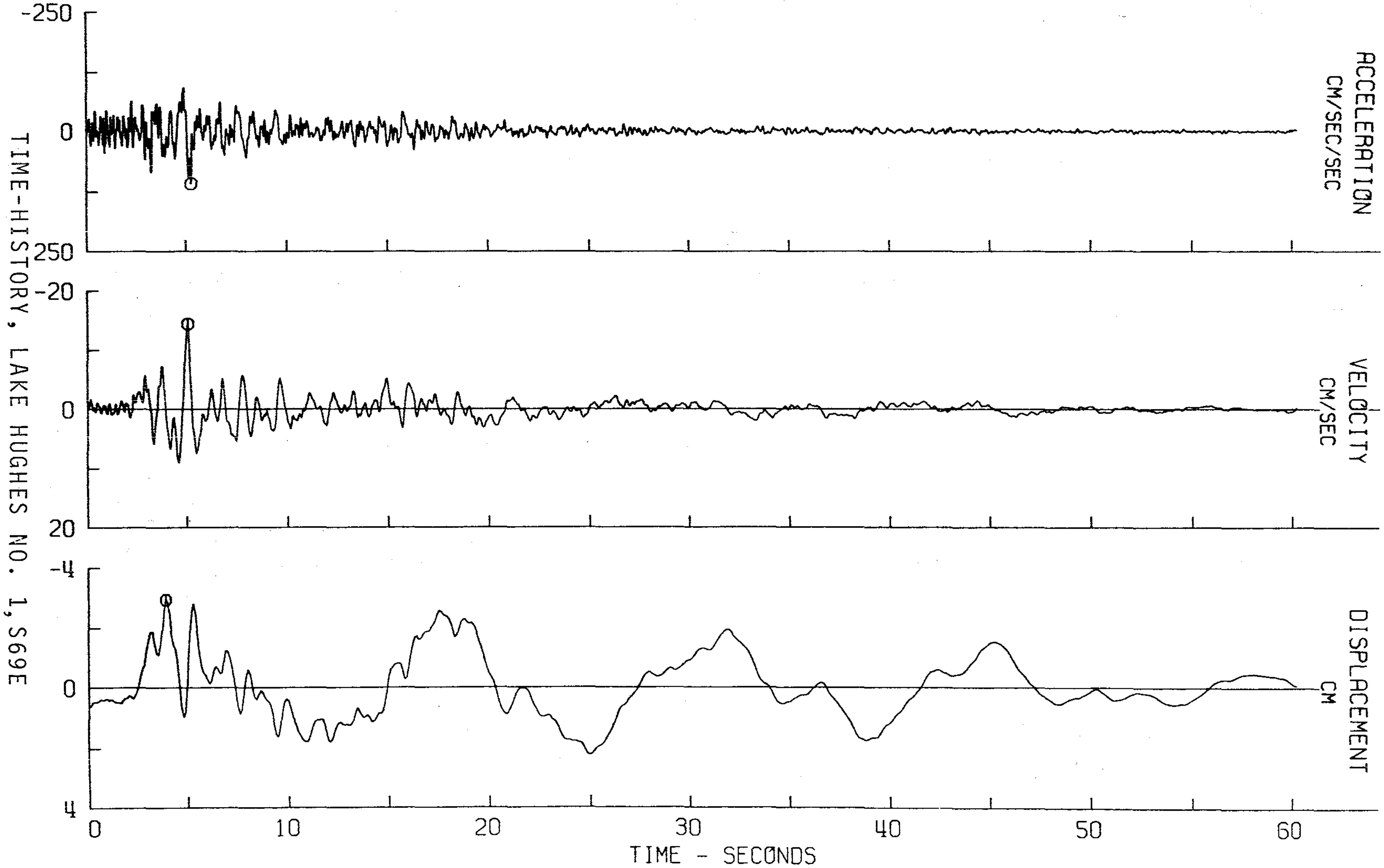
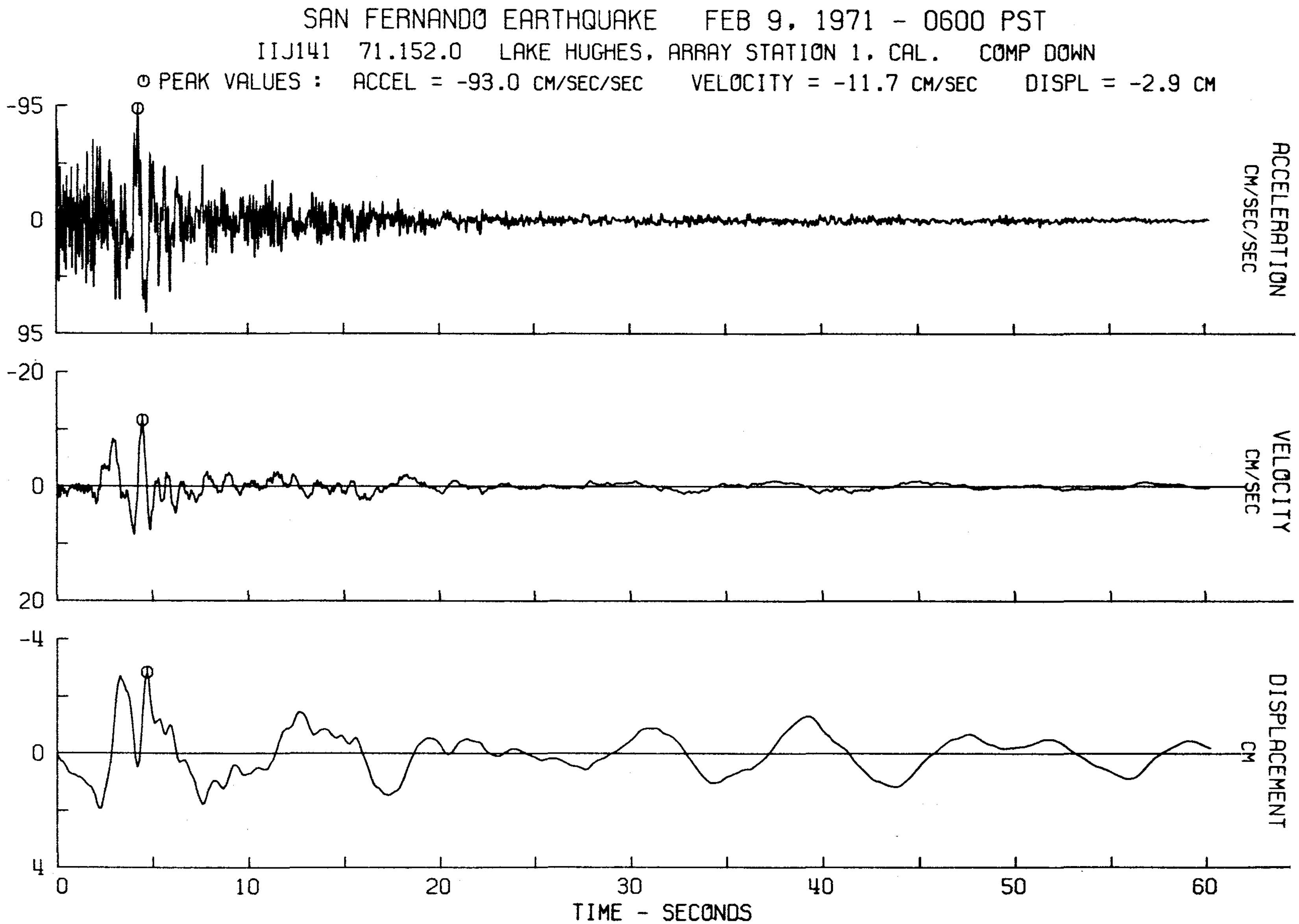


PLATE C-29



Ref: CIT/EERL 74-52

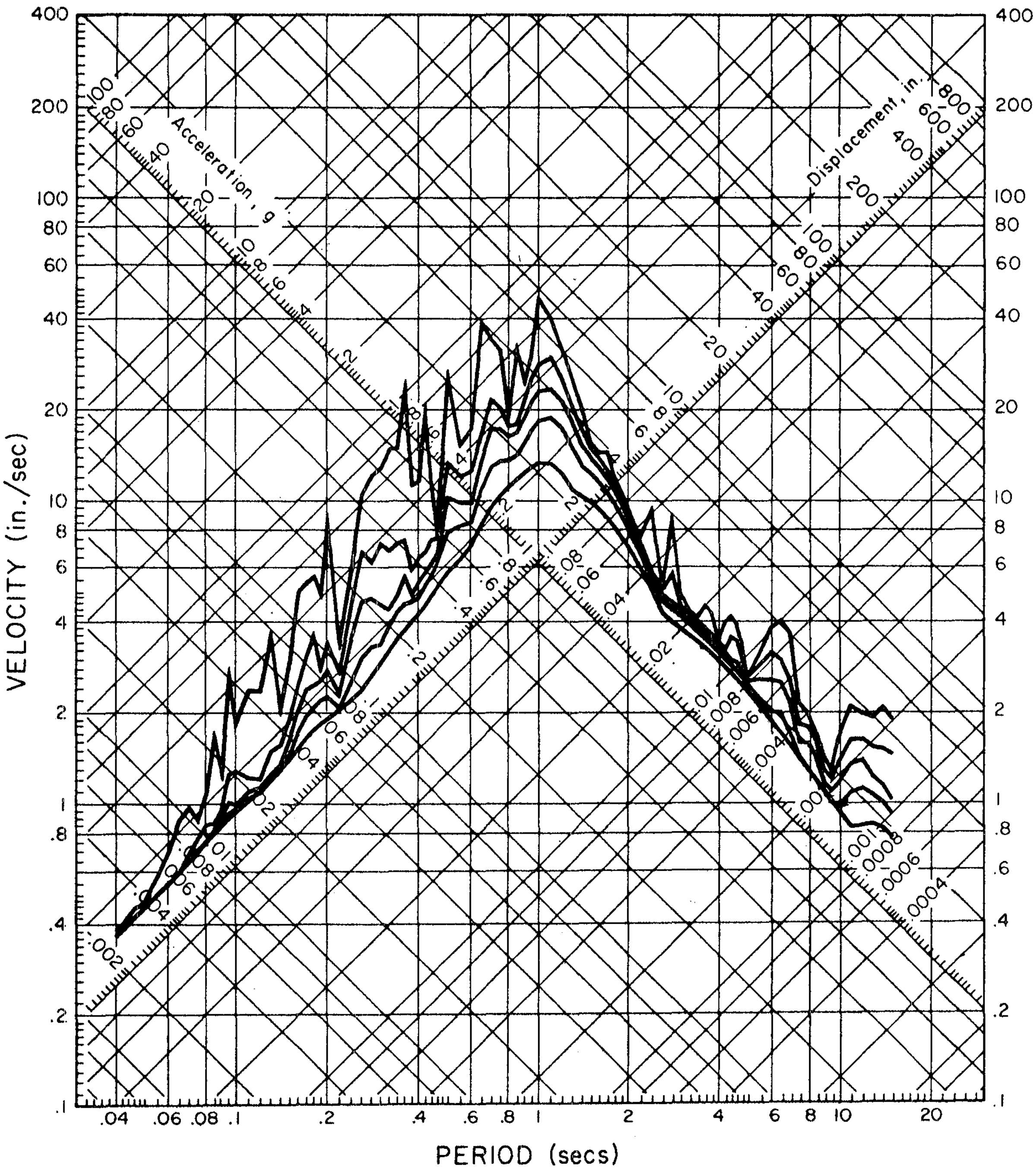
TIME-HISTORY, LAKE HUGHES NO. 1, Vertical

PLATE C-30

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIJ141 71.152.0 LAKE HUGHES, ARRAY STATION 1, CAL. COMP N21E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, LAKE HUGHES NO. 1, N21E

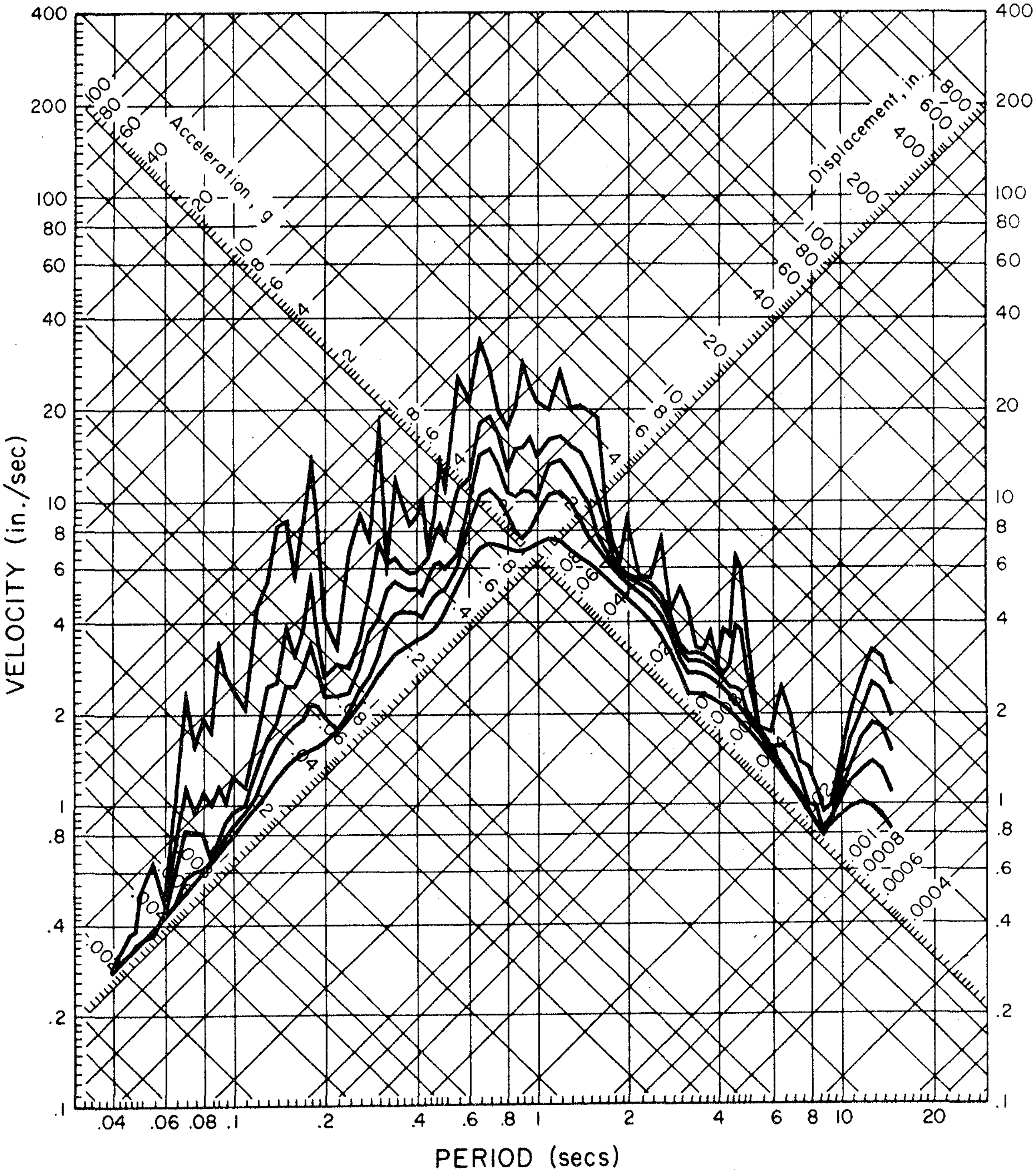
Ref: CIT/EERL 74-82

PLATE C — 31

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIJ141 71.152.0 LAKE HUGHES, ARRAY STATION 1, CAL. COMP S69E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, LAKE HUGHES NO. 1, S69E

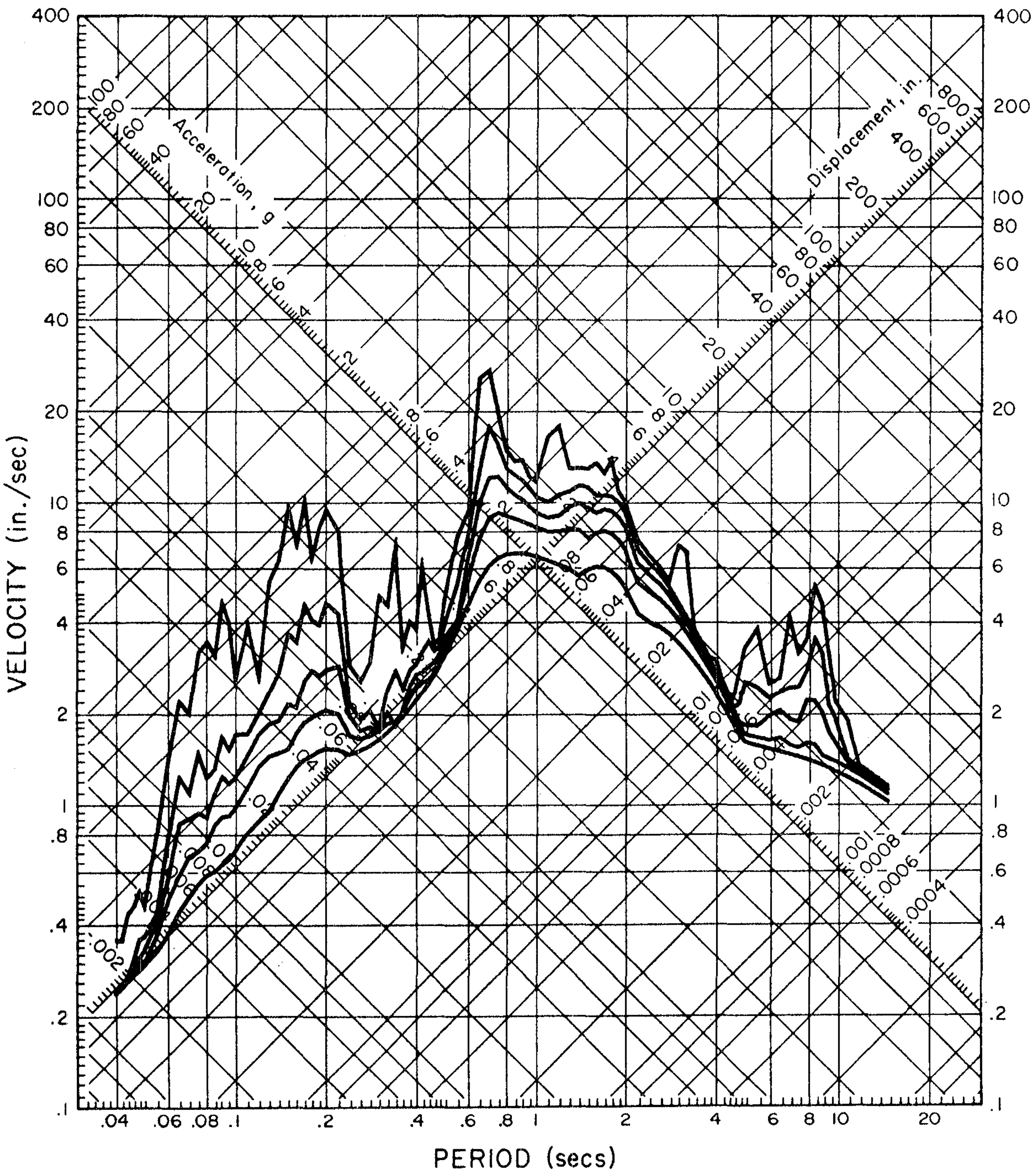
Ref: CIT/EERL 74-82

PLATE C-32

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIJ141 71.152.0 LAKE HUGHES, ARRAY STATION 1, CAL. COMP DOWN

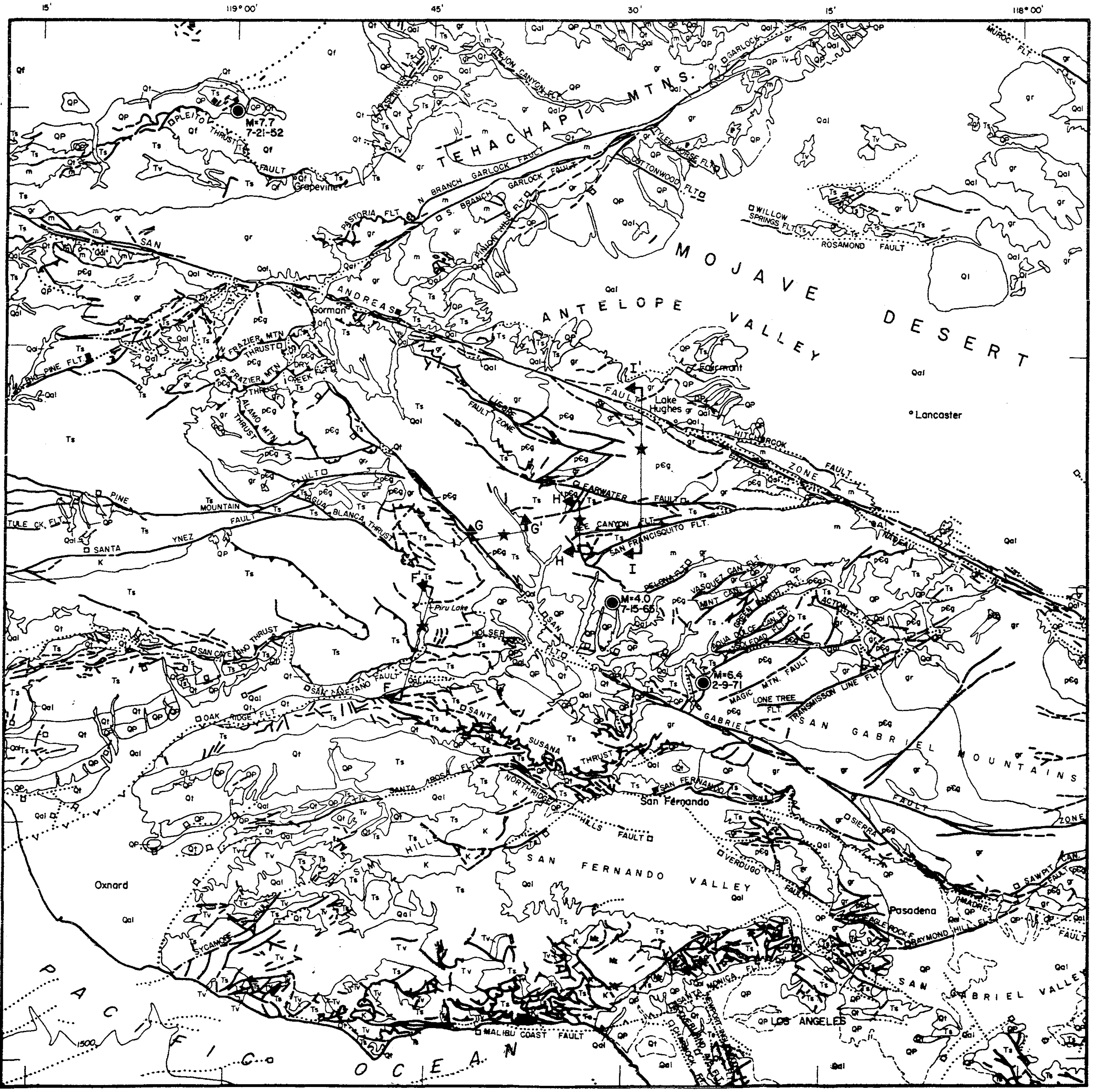
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, LAKE HUGHES NO. 1, Vertical

Ref: CIT/EERL 74-82

PLATE C-33



EXPLANATION

Qal	Alluvium, Holocene in age; includes dune deposits.
Qf	Stream channel, fan, and basin deposits, Holocene in age.
Ql	Lake deposits, Quaternary in age.
Qt	Marine deposits, marine and nonmarine terrace deposits, Quaternary in age; includes upper Pliocene marine deposits.
QP	Nonmarine sedimentary deposits, Plio-Pleistocene in age.
Tv	Volcanic rocks and igneous intrusive rocks, Tertiary in age.
Ts	Sedimentary rocks, Tertiary in age.
K	Sedimentary rocks, Cretaceous in age.
Mz	Mesozoic sedimentary rocks; also includes metamorphic rocks.
gr	Mesozoic granitic rocks; also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks.
m	Metamorphic and metasedimentary rocks, pre-Cretaceous in age.
P	Sedimentary and volcanic rocks, Paleozoic in age.
p€g	Precambrian igneous and metamorphic rocks; includes crystalline rocks which may be as young as Mesozoic.

★ Accelerograph Station location.

M=7.7 7-21-52 Epicenter location, Richter magnitude, and date of occurrence.

□ Faults that have moved during Quaternary time without historic record (approx. past 2 million years).

■ Faults that have moved during historic time (approx. 200 years).

Contact — Dashed where approximately located.

Fault — Dashed where approximately located, dotted where concealed, queried where existence is uncertain.

Thrust Fault — Barbs on upper plate, dashed where approximately located, dotted where concealed.

Offshore Fault — Location approximate.

NOTES: 1) Geology is simplified from Smith (1964), Jennings, Burnett, and Troxel (1962), Jennings and Strand (1969), Jennings (1962), Rogers (1967), and Rogers (1965). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975).

2) Information on fault activity (Quaternary activity, historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1975, for details).

3) Individual faults within the San Andreas fault zone show evidence of Quaternary and historic activity, (See Jennings, 1975, for details).

4) Heavy border on boxes indicates units that appear on this figure.

5) Earthquake magnitudes and epicentral locations are from Hudson, et al. (1969-1975a and b) and Hileman, et al. (1973).

Location of Geologic Map

Scale in miles: 0 5 10 15

Scale in kilometers: 0 5 10 15 20

Submarine contour interval 1500 feet

N

STATION	CROSS-SECTION & FIG. NO.	
Santa Felicia Dam	F-F'	5-14
Old Ridge Route	G-G'	5-15
Lake Hughes Array Station 12	H-H'	5-16
Lake Hughes Array Station 4	I-I'	5-17

GEOLOGIC MAP
LAKE HUGHES REGION
CALIFORNIA

LAKE HUGHES NO. 4
PLATE C-34

Ref: NUREG/CR-0055 Vol. 2

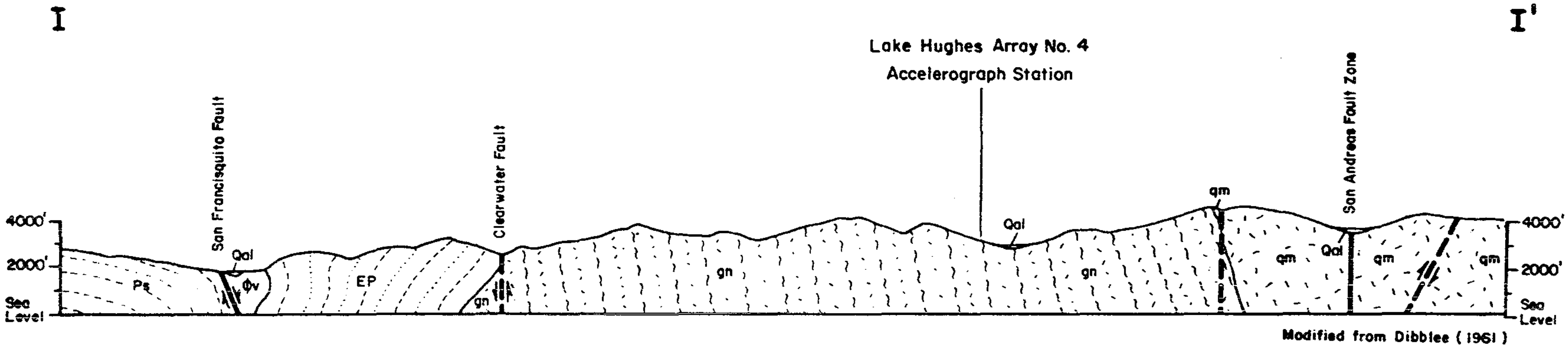
FIG. 5-13

GEOLOGIC CROSS-SECTION I-I'
LAKE HUGHES ARRAY STATION 4
LOS ANGELES COUNTY, CALIFORNIA

LAKE HUGHES NO. 4

PLATE C-35

Ref: NUREG/CR-0055, Vol. 2



EXPLANATION

Holocene	Qal	Alluvium; gravel, sand, and silt (Qal)
Miocene ? to Oligocene	Φv	Vasquez Formation; non-marine sandstone, siltstone, and shale (Ts)
Eocene to Paleocene	EP	Marine sandstone and shale (Ts)
Mesozoic	qm	Quartz monzonite; ranges in composition to granodiorite (gr)
Mesozoic ? Precambrian	gn	Gneiss and granitic rocks with an average composition of granodiorite (p€g)
Precambrian	Ps	Pelona Schist (p€g)

Notes:

1) Abbreviations in parentheses refer to geologic symbols used on Fig. 5-13.

2) For plan view of cross-section see Fig. 5-13.

0 1 2 3

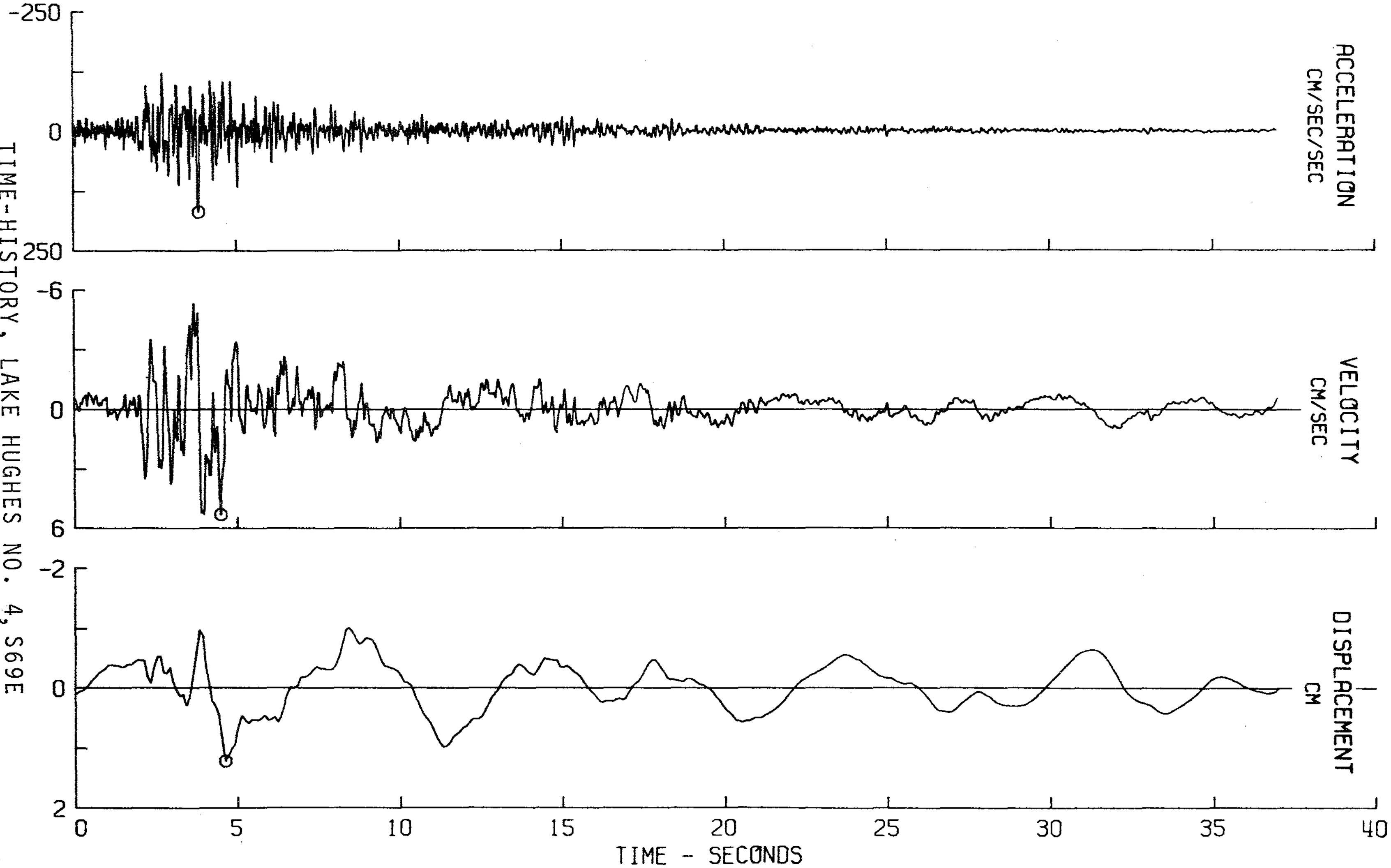
Scale in miles

Ref: CIT/EERL 74-52

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIJ142 71.065.0 LAKE HUGHES, ARRAY STATION 4, CAL. COMP S69E

⊙ PEAK VALUES : ACCEL = 168.2 CM/SEC/SEC VELOCITY = 5.3 CM/SEC DISPL = 1.2 CM



TIME-HISTORY, LAKE HUGHES NO. 4, S69E

PLATE C-36

Ref: CIT/EERL 74-52

TIME-HISTORY, LAKE HUGHES NO. 4, S21W

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIJ142 71.065.0 LAKE HUGHES, ARRAY STATION 4, CAL. COMP S21W

⊙ PEAK VALUES : ACCEL = -143.5 CM/SEC/SEC VELOCITY = -8.6 CM/SEC DISPL = 1.7 CM

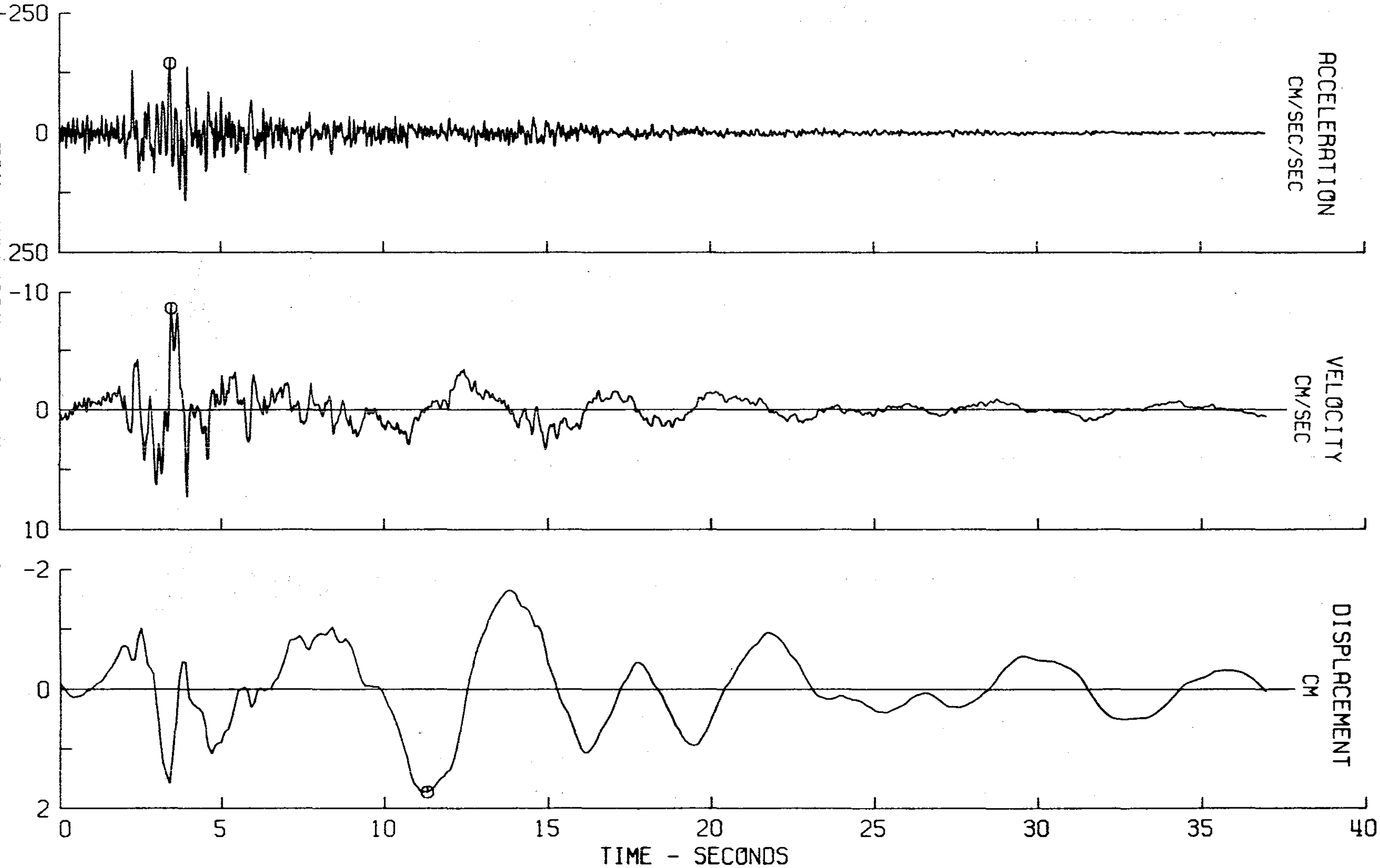
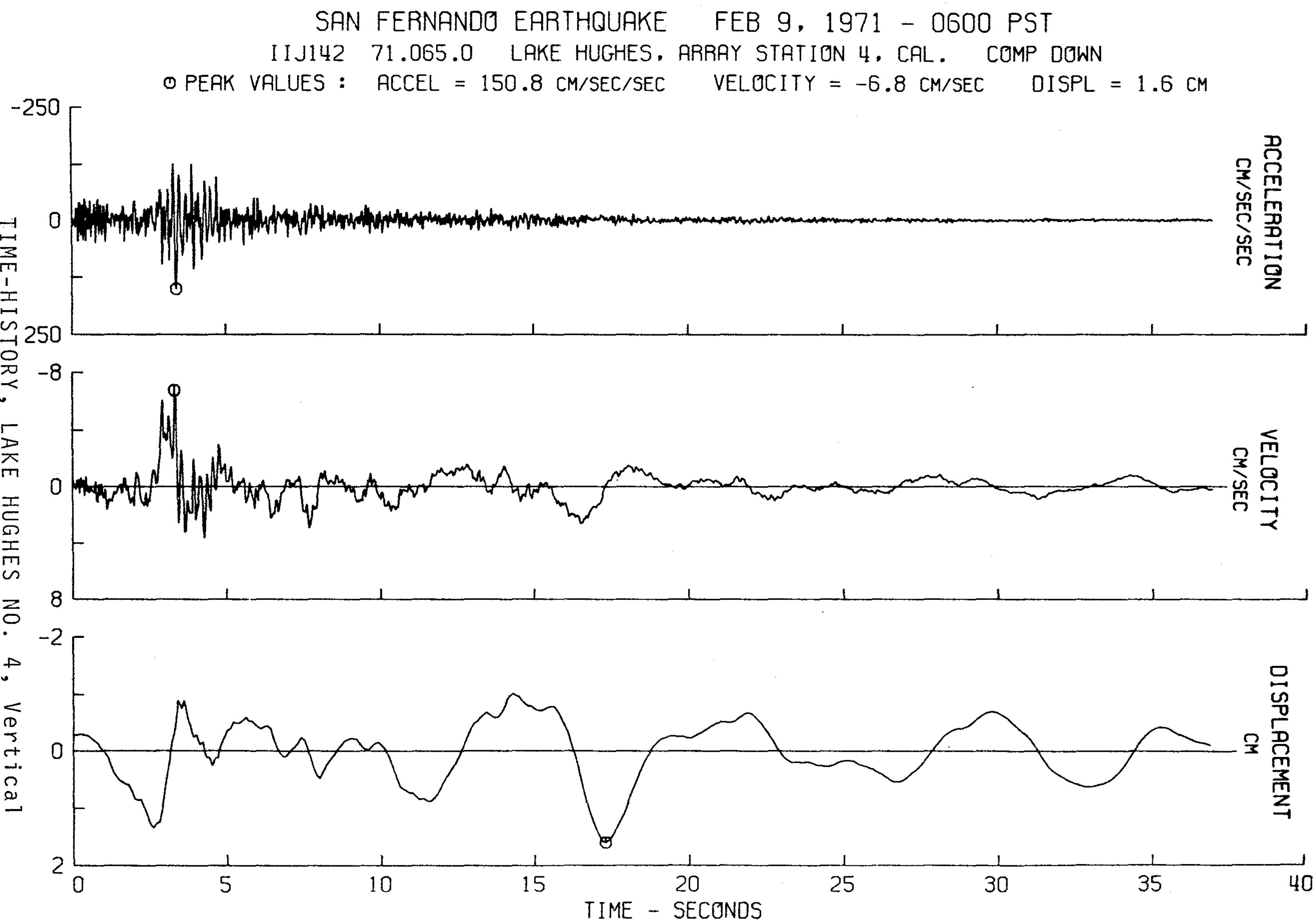


PLATE C-37



Ref: CIT/EERL 74-52

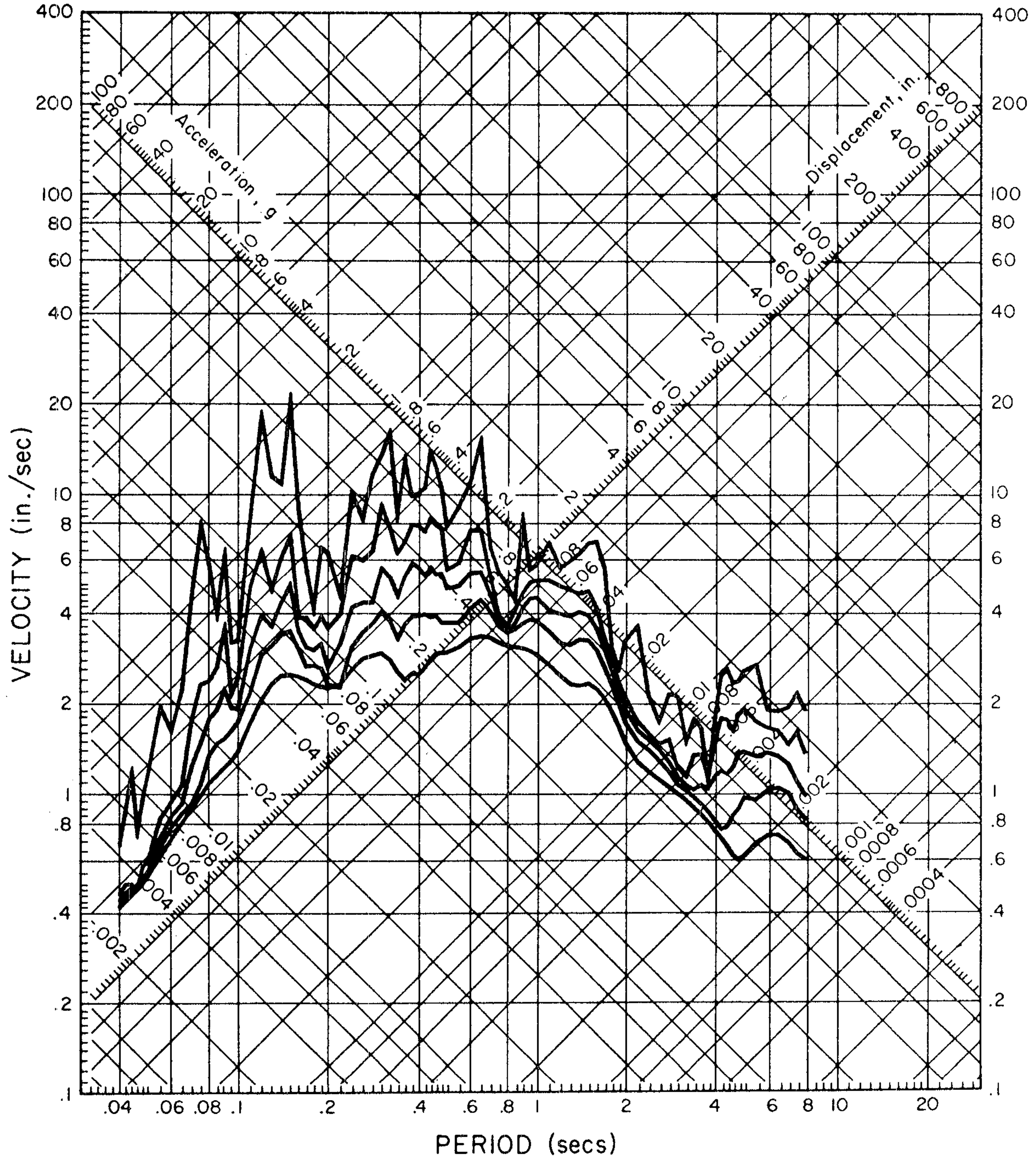
TIME-HISTORY, LAKE HUGHES NO. 4, Vertical

PLATE C-38

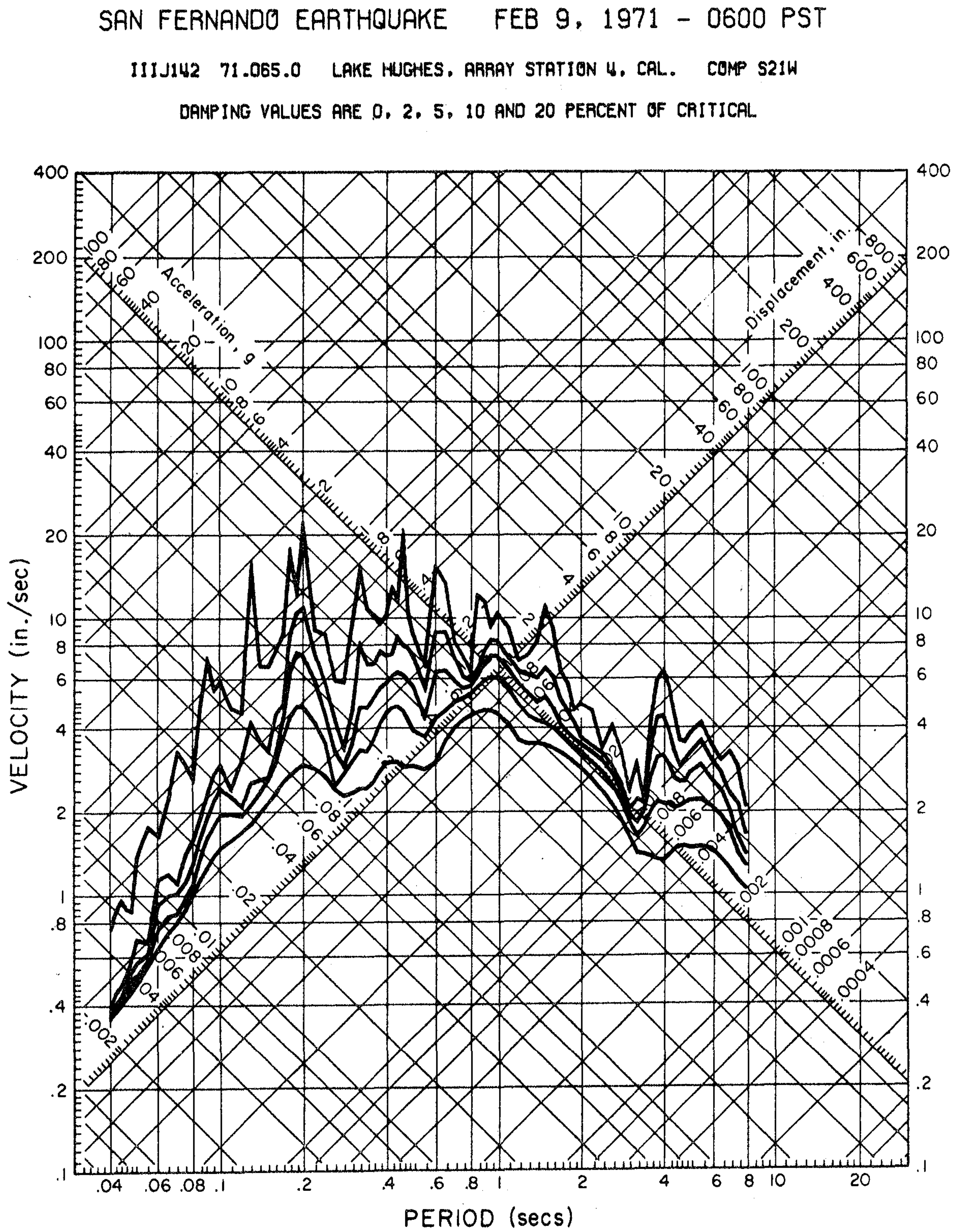
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIJ142 71.065.0 LAKE HUGHES, ARRAY STATION 4, CAL. COMP S69E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, LAKE HUGHES NO. 4, S69E



RESPONSE SPECTRUM, LAKE HUGHES NO. 4, S21W

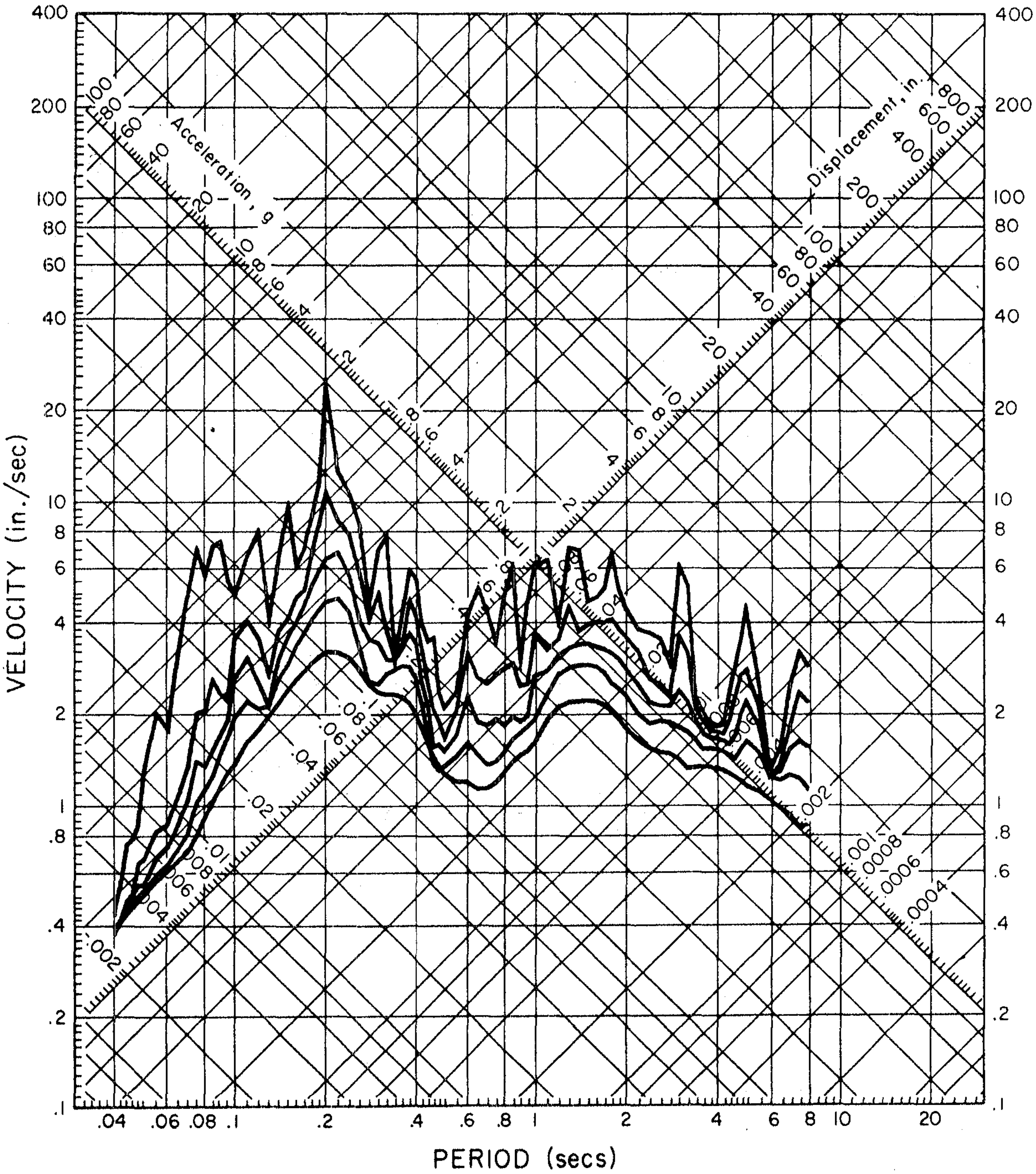
Ref: CIT/EERL 74-82

PLATE C-40

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIJ142 71.065.0 LAKE HUGHES, ARRAY STATION 4, CAL. COMP DOWN

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



RESPONSE SPECTRUM, LAKE HUGES NO. 4, Vertical

Ref: CIT/EERL 74-82

PLATE C-41

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15. Supplementary Notes

NASA Technical Monitor: Karl F. Anderson, NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California 93523-5000

16. Abstract

This report discusses a geological and seismological investigation of the NASA Ames-Dryden Flight Research Facility site at Edwards, California. Results are presented as seismic design criteria, with design values of the pertinent ground motion parameters, probability of recurrence, and recommended analogous time-history accelerograms with their corresponding spectra. The recommendations apply specifically to the Dryden site and should not be extrapolated to other sites with varying foundation and geologic conditions or different seismic environments.

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